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SOME PROBLEMS OF THE ROCKY MOUNTAIN PHOSPHATE FIELD.

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INTRODUCTION.

THE phosphate deposits of the Rocky Mountain region in the United States and Canada occur principally in rocks correlated with the Phosphoria formation of Permian age in Idaho. The Phosphoria formation is rather unique in American geology because it includes in close association over wide areas two very distinct types of rock not ordinarily found together and each in sufficient quantity to be a somewhat unique deposit in itself. The formation presents special problems in paleogeography and in sedimentation which involve the genesis of the phosphate rock and of the massive chert beds that make the formation noteworthy. Much information about the Phosphoria is already available but there is no connected story that gives a unified picture of it.

PHOSPHORIA FORMATION.

Name and Subdivisions.—The Phosphoria formation was named by Richards and Mansfield[2] from Phosphoria Gulch, a small canyon near Georgetown, Idaho, where the phosphate beds are well exposed (Fig. 1). This name was applied to the upper

[1] Presidential address delivered before the Geological Society of Washington, Dec. 10, 1930. Published by permission of the Director of the Geological Survey.

[2] Richards, R. W., and Mansfield, G. R., "The Bannock Overthrust," *Jour. Geol.*, vol. 20, pp. 684–689, 1912.

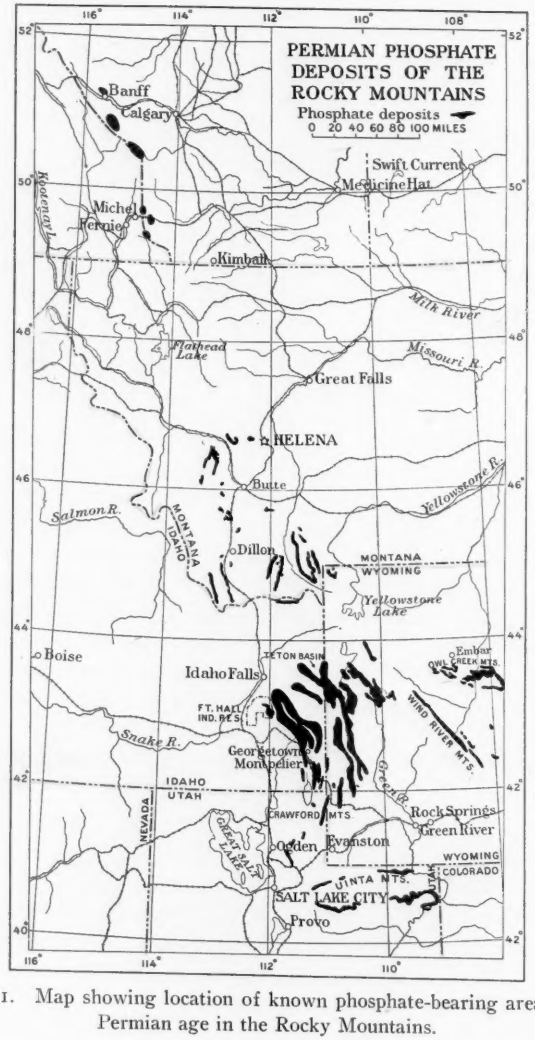

FIG. 1. Map showing location of known phosphate-bearing areas of Permian age in the Rocky Mountains.

two members of the Park City formation as formerly mapped in Utah and Idaho by Boutwell and Gale,[3] because in Idaho, at least, the lowest member of the Park City proved to be Pennsylvanian whereas the unconformably overlying beds had come to be regarded as Permian.

The upper unit or Rex chert member of the Phosphoria was named from Rex Peak in the Crawford Mountains, Utah. The lower unit comprises the phosphate shales.

General Distribution.—The Phosphoria formation is best developed in southeastern Idaho and adjacent parts of southwestern Wyoming and northeastern Utah, and it is in those areas that the thickest and richest deposits of phosphate are found, but phosphate beds correlated with the Phosphoria formation are found as far north as Banff in Alberta, as far east as the Owl Creek Mountains of central Wyoming, at numerous places in southwestern Montana, and along both flanks of the Uinta Mountains in Utah (Fig. 1).

General Character.—The outstanding characteristics of the Phosphoria formation are the large bodies of chert in the upper member and of phosphate rock and phosphatic shales in the lower member. Although the Rex chert member in certain districts contains considerable limestone, the limestone is absent over wide areas, so that thick and massively bedded cherts overlie directly the phosphate shales. The two members named lose their identity in certain parts of the field but the formation or its equivalents may be recognized in such areas by its faunal relations.

Lithologic Variations.—In the Park City district, Utah, the equivalents of the formation consist largely of calcareous members but also include several sandstones and quartzites and some beds of phosphate rock. In the Uinta Mountains Schultz[4] has divided the Park City formation into four members, of which the middle

[3] Boutwell, J. M., "Stratigraphy and Structure of the Park City Mining District, Utah," *Jour. Geol.*, vol. 15, pp. 434–458, 1907; Gale, H. S., and Richards, R. W., "Phosphate Deposits in Idaho, Wyoming, and Utah," *U. S. Geol. Surv.*, Bull. 430, pp. 457–535, 1910.

[4] Schultz, A. R., "A Geologic Reconnaissance of the Uinta Mountains, Northern Utah, with Special Reference to Phosphate," *U. S. Geol. Surv.*, Bull. 690, pp. 46–53, 1919.

two appear to correspond with the Phosphoria as developed in Idaho. The lowermost member is Pennsylvanian and the uppermost member is a thin-bedded gray limestone, which weathers readily. This last has no counterpart in Idaho unless it corresponds with the *Ambocoelia*-bearing beds found above the cherty beds of the Rex at one locality in the Fort Hall Indian Reservation.[5]

In the Georgetown Canyon district, Idaho, the phosphate shale member is about 160 feet thick and contains about 75% of shale, 17% of phosphate rock, and 8% of limestone. About 30 miles northwest a similar thickness of the shales contains only about half the percentages of shale and phosphate rock just given, whereas the percentage of limestone is greater and there is much sandstone.

In districts south of Montpelier, Ida., the Rex chert member consists mainly of black chert, dark cherty limestone, and a little gray limestone. At Montpelier a shaly bed is present in the chert. Farther north, except at a few localities, limestone is absent and the chert becomes largely a dark flinty shale with some beds of massive chert. Locally also there is a little quartzite in the section. Still farther north, in the Teton Basin district, the Rex chert member is composed largely of quartzite. In the same district the lower part of the phosphate shale member is more or less silicified, but higher beds are softer and contain much carbonaceous matter, which upon distillation yields small quantities of oil.

In Montana, as described by Stone[6] and Pardee,[7] the Phosphoria formation contains beds of phosphate rock at or near the base and these are overlain by cherty, sandy, or quartzitic beds. Limestone is practically absent, and the formation is on the whole more siliceous than it is in Idaho. In parts of Montana, as in

[5] Mansfield, G. R., "Geography, Geology, and Mineral Resources of the Fort Hall Indian Reservation, Idaho," *U. S. Geol. Surv.*, Bull. 713, p. 41, 1920.

[6] Stone, R. W., and Bonine, C. A., "The Elliston Phosphate Field, Mont., *U. S. Geol. Surv.*, Bull. 580, pp. 373–383, 1915.

[7] Pardee, J. T., "The Garrison and Philipsburg Phosphate Fields, Mont.," *U. S. Geol. Surv.*, Bull. 640, pp. 195–228, 1917. See also Condit, D. D., Finch, E. H., and Pardee, J. T., "Phosphate Rock in the Three Forks-Yellowstone Park Region, Mont.," *U. S. Geol. Surv.*, Bull. 795, pp. 147–209, 1928.

Wyoming,[8] the phosphate rock occurs at two principal horizons, one near the base and the other 20–60 feet higher, stratigraphically about the middle of the formation. The higher bed is by far the more extensive, being persistent over at least 25,000 square miles, including parts of Idaho and Utah in addition to the two States named. The lower bed, however, especially in Idaho, is the commercially productive one. This bed in Wyoming and Montana is distinguished by the abundance of the fossil *Lingulidiscina utahensis* and by an abundance of phosphatized shell fragments. In Idaho these features are only locally present, the lower bed being generally characterized by a lack of fossil remains.

In Wyoming the Embar formation, which is locally oil-bearing and includes beds correlated with the Phosphoria formation, is present in the Wind River and Owl Creek Mountains, but is said by Condit to change its character gradually northeastward and to become a gypsiferous red-bed series in the Big Horn Mountains.[9] Lee,[10] however, concluded from field observations that the Phosphoria beds in central Wyoming are cut off eastward by an unconformity and that the gypsiferous beds (Chugwater) lie above this. A section of the Phosphoria in the Wind River Mountains contains about 145 feet of beds that represent the phosphate shales. Of these beds only 5 per cent. is phosphate rock; the remaining 138 feet is limestone, which separates the phosphate beds at the bottom from those at the top.

At the Banff, Alberta, locality and in the various British Columbia occurrences[11] the beds corresponding with the Phosphoria formation are part of the group included in the so-called Rocky Mountain quartzite. They are of comparable thickness to the Phosphoria of Montana and Idaho but the main phosphate

[8] Condit, D. D. and others, *op. cit.*

[9] Condit, D. D., "Relations of the Embar and Chugwater Formations in Central Wyoming," *U. S. Geol. Surv.*, Prof. Paper 98, pp. 264–266, 1916.

[10] Lee, W. T., "Correlation of Geologic Formations between East-central Colorado, Central Wyoming, and Southern Montana," *U. S. Geol. Surv.*, Prof. Paper 149, pp. 9, 10, 1927.

[11] De Schmid, H. S., "Investigation of a Reported Discovery of Phosphate in Alberta," *Canada Dept. Mines*, Mines Br. Bull. 12, pp. 6–18. 1916, and Summary Rept. Mines Br. Dept. Mines for 1916, pp. 22–34, 1917.

bed at its best exposure is only 18 inches thick and is much leaner in phosphate than the better rock in those States. The phosphate rock is not oölitic but composed of many comminuted bone and shell fragments in a dark carbonaceous matrix. The phosphate beds are located approximately in the middle of the formation with beds of dark chert below and of lighter-colored chert and quartzite above. The position of these beds is suggestive of that of the upper bed in the Montana and Wyoming fields.

Faunal Relations.—When Girty studied the Phosphoria fauna in 1910,[12] he tentatively assigned it to the " upper Carboniferous " or Pennsylvanian on the strength of a few parallels that could be drawn with the Gschelian fauna as described by Tschernyschew because this fauna in the Russian section occupies a position immediately below the Artinskian or basal member of the Russian Permian. For the same reason he called the highest Paleozoic beds of Alaska, Gschelian or youngest Pennsylvanian. Girty later had opportunity to show his Alaskan collections, which had many similarities to those of the Phosphoria of Idaho, to Doctor Holtedahl, who had wide knowledge of Russian faunas. Doctor Holtedahl gave the opinion that the Alaskan fauna was really Artinskian (Permian) rather than Gschelian. Hence the Phosphoria has since that time been called Permian.

C. C. Branson,[13] in a recent study based chiefly on occurrences in the Wind River and Owl Creek Mountains of Wyoming, has concluded that the lower member of the beds which he interprets as Phosphoria is of late Pennsylvanian age and that there is a gradation without a break upward into lowermost Permian. On the other hand P. B. and R. E. King[13a] find elements of the Phosphoria formation " high above the Pennsylvanian, in the Leonard and Word formations [Texas], in association with cosmopolitan forms widely distributed in Europe and Asia."

[12] Girty, G. H., " Fauna of the Phosphate Beds of the Park City Formation in Idaho, Wyoming and Utah," *U. S. Geol. Surv.*, Bull. 436, 1910.

[13] Branson, C. C., " Paleontology and Stratigraphy of the Phosphoria Formation," *Univ. Missouri Studies*, vol. 5, No. 2, 66 pp., 16 pls. and map, April, 1930.

[13a] King, P. B. and King, R. E.: " Stratigraphy of Outcropping Carboniferous and Permian Rocks of Trans-Pecos Texas." Amer. Assoc. Petr. Geol. Bull. vol. 13, No. 8, p. 917, Aug., 1929.

Stratigraphic Relations.—At Embar post office on Owl Creek, Wyoming, the type locality of the Embar formation as originally defined by Darton,[14] the highest exposed beds are composed of a massive limestone that contains among other fossils the brachiopod *Spiriferina pulchra,* which is characteristic of the Rex chert. A few miles away this massive limestone is covered by yellowish sandy beds that Darton also included in the Embar. Blackwelder [15] has named these higher beds the Dinwoody formation, which Condit [16] has correlated with the Woodside and Thaynes formations (Triassic) of Idaho.

Mention has been made of the thin-bedded limestone recognized by Schultz as forming the uppermost part of the Park City formation in the Uinta Mountains and of the *Ambocoelia*-bearing beds above the cherty beds of the Rex in the Fort Hall Indian Reservation, Idaho. The occurrence of the Dinwoody in a similar stratigraphic position in the Wind River and Owl Creek Mountains of Wyoming lends point to the other two occurrences and raises the question whether these several sets of beds may not be remnants of a former widely distributed group now almost eroded away. A marked faunal break occurs between the Phosphoria and the Lower Triassic formations that succeed it in Idaho. This fact accords with the idea of widespread unconformity between the Permian and the Lower Triassic in the western phosphate field. It also harmonizes with Lee's view of unconformity between the Phosphoria and the Chugwater in central Wyoming.

Structural Relations.—The Phosphoria formation, in common with associated formations above and below, was folded and faulted during the great Laramide revolution and has experienced later structural disturbances. The displacements of the beds thus caused have led to their complete removal by erosion from certain

[14] Darton, N. H., "Geology of the Owl Creek Mountains," 59th Cong., 1st sess., S. Doc. 219, p. 18, 1906.

[15] Blackwelder, Eliot, "New Geological Formations in Western Wyoming," *Washington Acad. Sci. Jour.,* vol. 8, pp. 417–426, 1918.

[16] Condit, D. D., "Relations of the Embar and Chugwater Formations in Central Wyoming," *U. S. Geol. Surv.,* Prof. Paper 98, pp. 263, 264, 1916; "Phosphate Deposits in the Wind River Mountains, near Lander, Wyoming," *U. S. Geol Surv.,* Bull. 764, pp. 10, 11, 1924.

areas whereas in other places they have been down-folded or down-faulted and preserved. The phosphate shales have proved incompetent to transmit pressures and at certain places have been thickened, thinned, or faulted out during the processes of dislocation.

The Bannock overthrust and other similar thrusts traverse the region occupied by the Phosphoria formation. These faults have undoubtedly truncated the bottoms of the deeper phosphate-bearing synclines and thereby reduced the area that might otherwise be underlain by commercially valuable phosphate deposits. At other places beds of phosphate of suitable grade and thickness for commercial exploitation have been so buried or concealed by overthrusting that they are lost beyond reasonable hope of recovery, except perhaps where erosion of the upper fault block has revealed their presence in some window. These conditions affect all estimates of phosphate reserves and all plans for commercial exploitation of the phosphate.

The occurrences of the Phosphoria are now confined to more or less separated belts and irregular areas distributed through what was formerly a wide region but their total present area represents probably only a fraction of the original extent of the formation.

THE PHOSPHORIA SEA.

General Outline.—When the sea returned after the erosion interval, which succeeded Pennsylvanian deposition, it came apparently from the north and west, rather than from the southwest as in previous inundations. Its outline is not accurately known. The Phosphoria sea was probably closed off on the east and south but was possibly connected with the Pacific northwestward through Nevada and northern California and with the Pacific and Arctic by way of British Columbia and Alaska, as suggested in Fig. 2, which is modified from Schuchert's map.[17]

In a comprehensive study of the late Paleozoic in North America, published in 1919, Case[18] shows a land barrier extend-

[17] Pirsson, L. V., and Schuchert, Charles, "A Textbook of Geology, 2d ed., pt. 2, p. 355, New York, 1924.

[18] Case, E. C., "The Environment of Vertebrate Life in the Late Paleozoic in North America," *Carnegie Inst. Washington*, Pub. 283, p. 261, 1919.

ing northwestward from south-central New Mexico to the Canadian border. He notes that it may have been interrupted locally toward the north or was low enough there to permit the extension of red beds across it. West of this barrier red beds are

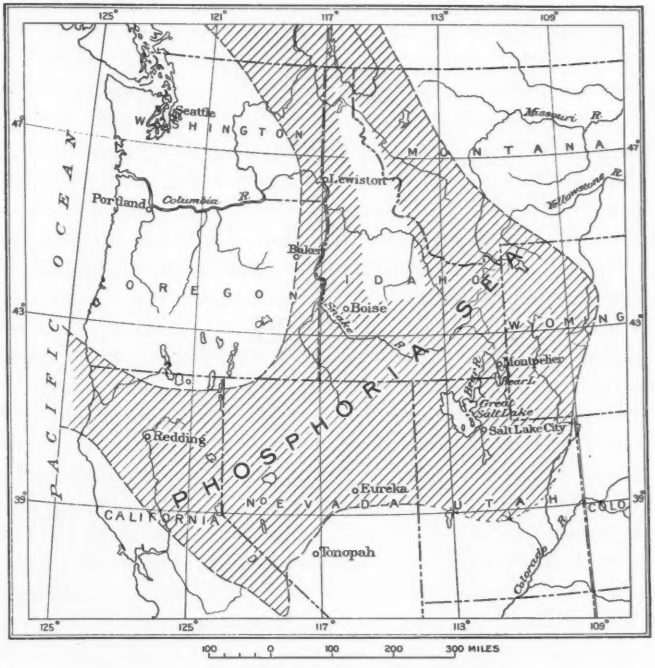

FIG. 2. Tentative map of the Phosphoria sea. Modified from Schuchert's paleogeographic map of the Permian.

generally absent, except as just noted, but towards the south they gradually replace the marine beds. In this paper Case does not assign western limits to this sea but in an earlier paper [19] he indicates its boundary as a line drawn northeastward from the southwest corner of Utah and northward through central Utah and

[19] Case, E. C., "The Permo-Carboniferous Red Beds of North America and their Vertebrate Fauna," *Carnegie Inst. Washington*, Pub. 207, Pl. 4, p. 88, 1915.

Idaho to Montana. On this map he also shows another sea extending eastward through California and southern Oregon into Nevada and southwestern Idaho. From the evidence in hand the writer prefers the interpretation given in Fig. 2, though he realizes that there are many gaps in present knowledge. This evidence has been discussed in detail elsewhere,[20] and need not be repeated here. The recent work of Branson and the Kings already cited indicates that there may have been an eastward extension of the sea, perhaps attenuated, as far as the Laramie basin in southeastern Wyoming, and possibly a southern arm extending into New Mexico and Texas, connecting with the Permian basin there.

During Phosphoria time a land mass of unknown extent and outline, or possibly a number of such land masses, probably occupied part of central Idaho and perhaps adjacent parts of western Montana, as well as some of the region farther north. It is not known whether these land masses were islands or simply irregular projections of the margin of the sea. The basis for this statement is in part the occurrence of rocks older than the Phosphoria within the area supposedly occupied by the Phosphoria sea. If those areas of older rocks were ever covered by the waters of that sea the deposits left by it have long since been eroded away. Another clew to the existence of these land masses is afforded by C. P. Ross's[21] discovery in the central Idaho region of volcanic rocks of supposed Permian age. In contrast to the fossiliferous marine volcanic tuffs of known Permian age in southwestern Idaho and eastern Oregon, the volcanics of central Idaho apparently accumulated on a land surface and are non-fossiliferous. Elevation accompanied by volcanic activity is thought by Case to have occurred about this time from Alaska southward into northern California.

The southern border region of the Phosphoria sea in Utah and northern Arizona was marked by the deposition of red beds, probably of either fluviatile or estuarine origin although the

[20] Mansfield, G. R., "Geography, Geology and Mineral Resources of Part of Southeastern Idaho," *U. S. Geol. Surv.*, Prof. Paper 152, pp. 184–188, 1927.

[21] Ross, C. P., Personal communication.

Kaibab limestone of Arizona [21a] indicates marine occupation there at least part of the time. Normal marine conditions are indicated by the fragmentary evidence in Nevada and California.

Conditions of Deposition.—The Phosphoria sea appears to have entered the continent on the north and northwest and to have overlain in part the Pacific positive element on the west. The Rocky Mountain positive element on the east formed a relatively unbroken barrier. These two elements, together with the islands just mentioned, supplied the terrigenous material now preserved in the Phosphoria formation. The red beds on the south and east borders of the phosphate-bearing areas suggest the presence in those directions of marginal playa seas analogous to the present Rann of Cutch in India, or of broad and shallow lagoons that maintained an interrupted connection with the Phosphoria sea, or perhaps of estuaries at certain localities. The limestones in the section indicate that the lands from which sediment might have been derived were relatively distant or so low that little waste from the lands mingled with the débris of the calcareous organisms. The presence of a chert bed containing sponge spicules and of other non-fossiliferous chert beds indicates that siliceous organisms also inhabited the sea and that silica as well as lime was supplied in solution from bordering lands. The great bodies of massively bedded cherts and of flinty shales in the Phosphoria formation seem to require some special source or condition of accumulation of the silica. The shales, sandstones and quartzites in certain districts indicate that these districts were nearer the shores of the sea or that neighboring lands were high enough or steep enough to furnish clastic material. The preponderance of sandy material at certain places may indicate either that the finer waste was carried farther into the sea and deposited beyond those localities or that only sandy terranes were available for the erosive agencies to act upon. The sea was relatively shallow, and its bottom, in common with the adjacent lands, suffered gentle oscillatory disturbances which led to the changes in sedimentation.

[21a] King, P. B. and King, R. E., *op. cit.*

CLIMATIC FLUCTUATIONS OF THE PERMIAN.

The Permian in many parts of the world was marked by glaciation. In North America thus far only one area of recognized glaciation has been reported, eastern Massachusetts, where tillite, probably of this age, has been identified. Sayles,[22] who has reported this occurrence, finds evidence that suggests interglacial epochs during that period.

Probably glaciation did not occur in the Rocky Mountain region of the United States in Permian time but climatic fluctuations in the area occupied by the Phosphoria sea may have taken place in response to the strongly marked climatic contrasts that existed elsewhere at this epoch.

PERMIAN-TRIASSIC INTERVAL.

At the close of the Permian the Phosphoria sea withdrew from southeastern Idaho and probably from much or all of the Rocky Mountain geosyncline as well. Although in the eastern United States and in Europe this time was marked by a great orogenic revolution, the disturbances in southeastern Idaho were so gentle that the attitude of the beds deposited in the Phosphoria sea was scarcely disturbed. Nevertheless, the faunal break between the upper beds of the Phosphoria and the lower beds of the overlying Lower Triassic is so great that a stratigraphic interval of some length is suggested. Farther north, in Montana, the crustal movement was probably more pronounced and the erosion interval longer, for, according to Condit, from the Idaho line south of Red Rock Lakes to the vicinity of Helena [23] the Jurassic beds truncate successively the Triassic formations and finally cut them out altogether.

THE PHOSPHATE BEDS AND THEIR PROBLEMS.

General Problems.—The phosphate beds represent a special phase of sedimentation during the Permian epoch. Although the

[22] Sayles, R. W., "The Squantum Tillite," *Harvard Coll. Mus. Comp. Zoöl. Bull.*, vol. 56, Geol. ser. 10, pp. 164, 169–170, 1914.

[23] Condit, D. D., "Relations of Late Paleozoic and Early Mesozoic Formations of Southwestern Montana and Adjacent Parts of Wyoming," *U. S. Geol. Surv.*, Prof. Paper 120, p. 114, 1928.

phosphate-producing agencies were doubtless at work throughout much of the sea during the earlier part of the Phosphoria epoch, their products were at some places so diluted with terrigenous or non-oölitic organic sediment that the resulting phosphate beds were thin or of poor quality. At other places where there was less dilution, a correspondingly thicker and richer accumulation of phosphatic material occurred.

The diastrophic oscillations which the sea bottom endured doubtless caused some differences in the rate and amount of deposition of the phosphate at different places.

The animal life of the Phosphoria sea consisted largely of invertebrates, chiefly brachiopods, and mollusks of different kinds, but there were some fishes, as shown by the spines and teeth now found here and there, and probably many siliceous organisms, though only sponges have thus far been actually indicated by the organic remains. The paucity of fossils in the beds of phosphate rock suggests the possibility that many soft-bodied animals without shells may have been present and may have assisted in the production of the phosphate. Certain shell-bearing types, of which the brachiopod *Spiriferina pulchra* is perhaps the most characteristic, were widely distributed in the later part of the epoch.

Plant life is thought by Condit [24] to have played a leading rôle in the development of phosphate. He calls attention in this connection to the phosphate beds in the Dillon district, Mont., where, he says, "the richest and thickest phosphate bed lies in the midst of a thick dark shale that is richer in shale oil than any other part of the section. Yet this shale and the phosphate bed contain few fossils and are only slightly calcareous." These ideas are in line with the earlier view advanced by Breger [25] that the conditions attending the origin of the oil and phosphate in the Lander region, Wyo., were comparable to those of a Sargasso sea.

The suggested relation of dark shales rich in shale oil to rich phosphate beds is perhaps negatived by earlier results obtained by

[24] Condit, D. D., Finch, E. H. and Pardee, J. T., *op. cit.*, p. 175.

[25] Breger, C. L., "Origin of the Lander Oil and Phosphate," *Min. and Eng. World*, vol. 35, p. 632, 1911.

Condit [26] himself in his examination of the phosphate shales in southeastern Idaho and southwestern Wyoming. The shales in those regions yielded practically no oil in spite of the fact that they contain the richest known phosphate beds in the entire western field. The hypothesis that marine plants may have played an important part in the formation of the phosphate shales is attractive in so far as it applies to the accumulation of carbonaceous matter and hydrocarbons in the shales. They could not, however, have furnished any phosphate, so that the chief rôle in the formation of that material must still be assigned to animal life.

One of the minor constituents of phosphate rock that may shed a little light on the general conditions of its time of deposition is fluorine. Zies [27] has shown that the fumaroles of the Valley of Ten Thousand Smokes in Alaska alone contribute annually to the sea about 135,000 metric tons of fluorine. He states that the quantity of fluorine stored in the estimated phosphate reserves of the Idaho field approximates 540,000,000 metric tons. Since volcanic emanations form the principal source of fluorine in the sea, this perhaps constitutes independent evidence of volcanic activity on a considerable scale during Phosphoria time.

Special Features.—The phosphate is generally well bedded and without ripple or current markings or crossbedding. Beds of phosphatic shale and impure limestone are interstratified with beds of phosphate. The most characteristic feature of the phosphate itself is oölitic texture. Nodules of phosphate or of limestone though present at some localities are relatively exceptional in the better rock. The phosphatic grains are generally pure oölites with concentric structure and not casts of Foraminifera or other organisms but in some localities certain beds are composed essentially of comminuted and phosphatized shell fragments, and in certain areas, for example, the Wind River Mountains, the lower phosphate bed consists in larger part of fossils, the shells of which have

[26] Condit, D. D., "Oil Shale in Western Montana, Southeastern Idaho, and Adjacent Parts of Wyoming and Utah," *U. S. Geol. Surv.*, Bull. 711, p. 29, 1920.

[27] Zies, E. G., "The Valley of Ten Thousand Smokes," *Nat. Geog. Soc.*, Contrib. Tech. papers, Katmai ser., vol. 1, No. 4. pp. 65–73, 1929.

been phosphatized.[28] The most valuable beds commercially are made up of aggregates of phosphate oölites cemented by minor amounts of the same phosphatic substance.

Glauconite, which commonly accompanies recent phosphate nodules and has been found in many of the European and North African phosphate deposits, is absent from the Phosphoria formation throughout much of its extent, but Condit[29] reports granules of possible glauconite in the deposits near Lander, Wyo., and Branson[30] states that the top limestone of the formation in the Owl Creek Mountains is highly glauconitic. The basal beds at some localities, as on the west side of the Teton basin, are nodular or even conglomeratic, and the pebbles of the conglomerate consist largely of oölitic phosphate. At other places beds of shale, sandstone, limestone or even phosphate rock directly overlie the Pennsylvanian rocks.

Though the phosphate beds themselves are practically non-fossiliferous over large areas, some accompanying strata such as the so-called " cap lime " near Montpelier carry a considerable fauna. At some places, too, the phosphate beds themselves are fossiliferous. Thus in the Wind River and Owl Creek Mountains, according to Condit[31] the upper phosphate bed contains *Productus nevadensis*, and *Lingulidiscina utahensis* is extremely abundant in the lower bed. The faunas of the Phosphoria in these regions have recently been described by Branson.[32]

In some of the richest sections, the total thickness of phosphate beds is as much as 30 feet, and over wide areas in southeastern Idaho it is not much less than 10 feet. Besides these oölitic beds there are shales and limestones that are more or less oölitic and phosphatic.

Origin.—The oölitic grains of phosphate are built into successive layers in the same manner as the clastic materials with which they are associated. They must therefore have existed in the

[28] Condit, D. D., " Phosphatic Deposits in the Wind River Mountains near Lander, Wyoming," *U. S. Geol. Surv.*, Bull. 764, p. 35, 1924.

[29] *Ibid.*, p. 13.

[30] Branson, C. C., *op. cit.*, p. 11.

[31] Condit, D. D., *op. cit.*, footnote 16, pp. 11–13, 1924.

[32] Branson, C. C., *op. cit.*

form of phosphate when they were thus assembled. Some secondary action of solutions bearing calcium carbonate and phosphates is indicated by the formation of nodules and by the phosphatization of the shell fragments already noted. Some thin sections of oölitic phosphate show that calcite, both in the oölitic grains and in the matrix of the rock, has been replaced by phosphate.

The mode of origin of the oölites is not clearly understood, but the presence on the sea bottom of solutions rich in phosphate or perhaps of phosphatic colloids is certainly indicated. The oölitic grains appear to have been formed directly from these, perhaps partly by chemical precipitation and partly by physical or mechanical accretion. Bacteria may have played a part. Analogies are furnished by certain iron-bearing deposits in the formation of which bacterial action is more or less clearly established. Moreover a group of phosphate bacteria, which specialize in the assimilation of phosphate from soil solutions, is reported [33] but it is not known if similar bacteria are active in marine habitats.

David White [34] has suggested that algae may have played some part in the formation of the phosphatic nodules. The "minute, curly, hair-like, and branching plant fragments" noted in some of the phosphate ovules [35] may have some bearing on this suggestion.

The quantity of phosphatic material represented by the phosphate beds has led some to think that an unusual source of supply must be looked for. Blackwelder,[36] for example, has suggested a possible wholesale killing of fishes by changes of currents or temperatures in the ocean. Although this idea has some precedent in actual historic instances, it hardly seems applicable to the Phosphoria formation. Under such an hypothesis more fish remains should be found in the deposits than actually appear. Moreover the conditions of deposition already discussed imply slow accumulation over a long period of time and with time enough even a slow

[33] Stoklasa and others, cited by C. L. Breger, *op. cit.*

[34] Personal communication.

[35] Mansfield, G. R., *op. cit.*, p. 213.

[36] Blackwelder, Eliot, "Origin of the Rocky Mountain Phosphate Deposits," *Geol. Soc. Amer. Bull.*, vol. 26, pp. 100–101, 1915 (abstract).

rate of deposition would produce large amounts of phosphate. Pardee [37] has called attention to the widespread glacial conditions of Permian time and has pointed out that such conditions would favor the accumulation of carbon dioxide in the sea water and that this condition would be less favorable to the precipitation of calcium carbonate than to that of phosphates.

The water circulatory system throughout much of the Phosphoria sea must have been poor, otherwise the conditions of the bottom would not have become so foul. Probably the inflow of sea water from the North Pacific or Arctic was impeded and the temperature contrasts between higher and lower latitudes may not have been so pronounced as they are to-day. At any rate, conditions were not as favorable for replenishment of oxygen in the deeper waters of the Phosphoria sea as they are in open oceans. This fact prevented the growth on the sea floor of ordinary organisms of the scavenger type. On the other hand, it promoted anaerobic bacterial decay, so that decomposition products such as carbon dioxide and ammonium phosphate might readily be produced.

According to Credner,[38] the calcium phosphate of fish remains after its extraction with water containing carbon dioxide, will, in the presence of ammonium carbonate, react to form calcium carbonate and ammonium phosphate. This last substance with addition of more calcium carbonate changes again to calcium phosphate and ammonium carbonate. These conditions, which have been reproduced in the laboratory, are believed to be present on the sea bottom where a cycle of chemical reactions takes place among such solutions by which bits of shell and other objects become phosphatized. Tricalcium phosphate in the form of collophanite or of carbophosphates, such as dahllite, may be precipitated chemically in colloidal or amorphous form or may perhaps be abstracted from solution by bacteria as above suggested. Small objects or fragments of various sizes and kinds may serve as nuclei for nodules or oölites or the oölites may form without any core of foreign

[37] Pardee, J. T., "The Garrison and Philipsburg Phosphate Fields, Mont.," *U. S. Geol. Surv.*, Bull. 640, pp. 225–228, 1917.

[38] Credner, H., "Die phosphatische Knollen des Leipzig Mitteloligocene," *K. sächs Gesell. Wiss. Abh.*, Band 22, p. 26, 1895.

material. The conditions of chemical equilibrium at the sea bottom are unknown but the presence of beds of phosphatic limestone in association with beds of phosphate appears to indicate that changes in concentration of the various constituents of the solutions at the sea bottom were perhaps controlling factors in determining which substance should be deposited.

Economic Importance.—According to recently published estimates,[39] which are incomplete, the Rocky Mountain phosphate field in the United States contains reserves of phosphate amounting to more than six billion metric tons. This makes it one of the three great phosphate fields of the world, the other two being North Africa (including Tunisia, Algeria, Morocco, and Egypt) with more than four billion, and Russia (including Siberia) with more than six billion. The reserves in Idaho, which constitute about five-sixths of those mentioned for the Rocky Mountain field, range from 60 to more than 70 per cent. in tricalcium phosphate content and are thus richer in phosphate than those of the other fields named except those of Morocco, which are comparable in grade to the best Florida phosphates (70–78 per cent.). The Rocky Mountain field, however, is more remote from existing markets than are the much smaller phosphate fields of Florida and Tennessee, which thus yield the bulk of present production. Production in the Rocky Mountain (western) field has usually amounted to less than two per cent. of the total for the country but is none the less significant. In 1929 the quantity mined was 42,634 long tons but in 1925, the banner year, this quantity was 83,802 long tons.[40]

THE REX CHERT.

General Interest.—A discussion of the great chert-bearing member of the Phosphoria formation, the Rex, should be of general interest to economic geologists because of the association of cherts in various relationships with deposits of iron ore in the Lake

[39] Mansfield, G. R., "Phosphate Deposits of the World" (pp. 94–107, World Conditions as to Mineral Raw Materials for the Fertilizer Industry), Nat. Fertilizer Assoc., Washington, D. C., 1926.

[40] Johnson, B. L., *U. S. Bur. Mines, Min. Res.*, Phosphate Rock in 1929, p. 342. 1931.

Superior region and elsewhere and with other metalliferous deposits such as the lead and zinc ores of the Mississippi Valley.

Special Features of the Rex.—The massively bedded chert usually forms rocky ledges, fine dip slopes, or impressive gateways. No laminae of shale have been observed in it but bedding planes are well developed and characteristically marked by surfaces with low humps and hollows suggestive of nodular structure. The flinty shale facies is usually not well exposed, for the thin beds are so thoroughly jointed that the rock ordinarily breaks into small chippy fragments, which form rounded hills or smooth slopes. Banding is not a common feature but has been observed at a few places.

The texture of the massively bedded chert is usually very fine and even. The rock breaks with conchoidal fracture into rough angular pieces. Near the base at some localities is a coarser-textured bed composed largely of the spicules of siliceous sponges. In thin section all gradations from cross sections to longitudinal sections may be observed. This bed appears to be widespread. The texture of the flinty shale facies is not so fine and on freshly fractured surfaces it appears more earthy.

Such slides of the massively bedded chert as have been examined show feebly polarizing cryptocrystalline quartz throughout without chalcedony or amorphous material. Slides of the basal bed, in which the sponge spicules are so numerous, contain chalcedony, chiefly in the walls of the spicules, and some streaks of apparently amorphous material discolored by organic matter or by iron oxide. Little or no organic detrital material has been recognized.

Little variation in composition may ordinarily be noted in any one area, yet within the broader region occupied by the formation as a whole considerable differences may be observed. Thus in the Montpelier district and in areas farther south and southeast the Rex chert interval contains more or less limestone whereas on the west side of the Teton basin some hundred miles or more to the north the Rex contains quartzite in its upper part. Fossils in the Rex occur chiefly in the limestones but at one locality numerous casts of crinoid stems were found in the chert.

The massively bedded facies alone ranges from about 60 to 110 feet in thickness and appears to have been in simultaneous process of formation throughout much of the great area occupied by the Phosphoria formation.

Other Cherts.—Other cherts that have more or less in common with the Rex are the radiolarian cherts of Franciscan age in California, the cherts of the Monterey group in California, which contain no radiolarian remains but are otherwise much like the Franciscan cherts, the cherts of Missouri and adjacent regions and certain cherts described from Ireland, Wales, Yorkshire, and Spitzbergen. A considerable literature has sprung up about each of these occurrences but it is not practicable to consider this here.

Discussion has centered about such questions as the sources of the silica, whether organic or inorganic, and the mode of deposition, whether directly as organic remains, indirectly by diffusion and through replacement of limestone, or directly through chemical precipitation.

Tarr's Hypothesis of Origin.—Among the most recent contributors to the theory of chert formation is Tarr,[41] who has studied intensively both the cherts of the Missouri region and those of the British Isles. His conclusion, after a consideration of the literature of the subject and in the light of his own field and laboratory studies, is about as follows:

During periods of low-lying lands, stream-borne colloidal silica tends to accumulate in the sea partly because of protective or hydrophilic sols and is finally precipitated quite rapidly. The weight of later-deposited materials compresses the gel-like mass. Subsequent changes involve loss of water, contraction and slow changes to opal, chalcedony and quartz.

Application to Rex Chert.—Tarr, in common with numerous other writers, recognizes the difficulty in assigning the principal rôle in chert formation to siliceous organisms. They are too few in number to account for the great accumulations of chert, and when present they seem to be incidental rather than causative. In the Rex chert aside from the sponge spicules in the basal bed there

[41] Tarr, W. A., "The Origin of Chert and Flint," *Univ. of Missouri Studies*, vol. 1, No. 2, p. 24, April 1, 1926.

is no suggestion of siliceous organisms. On the other hand the occurrence of casts of crinoid stems in the chert as previously noted indicates that occasional organic remains became entombed in the chert when it was soft and were later dissolved away.

So far as ascertained the paleogeographic conditions of late Phosphoria time approached the optimum required by Tarr's hypothesis. There seem to have been lowlands or peneplaned lands adjacent to the Phosphoria sea and an abundance of sandy and quartzitic material in Pennsylvanian and other terranes exposed to erosion. Volcanic tuffs and solutions may have contributed to the supply of silica.

A similar condition of low-lying lands is also postulated for early Phosphoria time, when phosphate was being deposited in large amounts and silica only incidentally or locally. Possibly at that time siliceous terranes were less well exposed or, pushing Tarr's hypothesis a little farther, the quantity of organic matter present in the Phosphoria sea during the earlier epoch provided sufficient hydrophilic sols to inhibit for a prolonged period the precipitation of the silica. However, this may be, the writer is disposed to regard some method of chemical precipitation as the most probable mode of accumulation of the chert.

The objection that no deposits of gelatinous silica have been recognized in modern oceanic sediments may lose some of its force when it is remembered that the present is a time of world-wide continental elevation. There is probably nowhere along the borders of the oceans to-day a terrane of lowlands or a peneplain such as that suggested for the lands surrounding the Phosphoria sea, or that approaches quite the conditions postulated by Tarr's hypothesis.

Various authors have pointed out associations of phosphate and of silica with erosion surfaces and it is true that the Phosphoria formation is bounded both below and above by unconformities. The writer, however, has thus far been unable to trace any genetic relation between these features and the beds of phosphate or chert that distinguishes the Phosphoria from other non-phosphatic or non-siliceous formations similarly bounded by unconformities.

SUMMARY.

The Phosphoria formation records the presence of a former sea, whose area is now only imperfectly known. The waters of this sea deposited moderate amounts of the ordinary kinds of sediment but unusual conditions permitted them also to lay down great bodies of phosphatic and siliceous sediments. These originated in part through organic agencies but seem to owe their major accumulation very largely to chemical precipitation.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

THE VEINS AND CROSSINGS OF THE GRASS VALLEY DISTRICT, CALIFORNIA.

JOHN B. KNAEBEL.

INTRODUCTION.

Statement of the Problem.—The gold-quartz veins of the Grass Valley district are fissure deposits having in general flat dips of 25° to 30°, and persistent strikes in two general systems, one north-south, the other east-west.

Intersecting the veins, at angles of 10° to 90° with their strike, are zones of nearly vertical fissuring, locally known as "crossings." These crossings affect the veins in various ways, such as causing local deviations in dip and strike, or changing the character of the ore. It is recognized in the district that the character of vein matter and the grade of ore frequently undergo marked changes as a vein approaches or leaves a crossing. For example, in the lower workings of the Empire mine, in the region of a strong crossing, the vein has changed its attitude from one of flat dip to a much higher inclination ranging from 45° to 70°; its strike is no longer persistent, but has given way to *en echelon* arrangement of parallel mineralized fissures of rather limited extent.

In the lean or barren areas, where the veins dwindle to relatively small thickness, carbonates frequently take the place of quartz, and the filling closely resembles that typical of crossings. This character, coupled with the steeper dips in depth, often gives rise to some doubt as to whether a given development heading is being driven on the vein, with some prospect of encountering ore, or whether it is following a crossing fissure. In the latter event, work should be stopped, for true crossings have never in the history of the district carried ore in sufficient quantities to pay the cost of mining.

The present paper is the result of an investigation undertaken

with the object of establishing, if possible, criteria by means of which the vein filling of the lean or barren areas could be distinguished microscopically from crossing material. Positive results, it was believed, might prove valuable as aids to planning and carrying on development work.

During the course of the work, certain features were noted that are not strictly pertinent to the question at hand, but are of interest in connection with the origin of the veins and the deposition of ore. Consequently, these features are presented with a brief discussion of their significance.

Location and History of the District.—The Grass Valley district is situated in Nevada County, California, about 25 miles north of Auburn and 12 miles northwest of Colfax. Lindgren [1] has so fully described its location, topography, vegetation, literature, and history that a detailed treatment of these phases of the subject need not be given here.

Lode-gold was first discovered in the district in 1850, the Empire mine was opened up in 1851, and by 1894 all the mines covered by the present investigation were producing, including the Empire, W. Y. O. D., Pennsylvania, Orleans, Sultana (Osborne Hill), New York Hill, and North Star. The entire group is now operated by the Newmont Corporation through the Empire, Pennsylvania, and Central North Star shafts.

The first important geologic studies were made by Lindgren in 1894, and his published report [2] is so exhaustive, and so accurate, as demonstrated by subsequent work, that it is still regarded as a classic. Since the descriptive work of Lindgren, other geologists have studied the mines, but little has been published by any of these except Howe. He did considerable work in the North Star mine, and contributed much to the fund of present knowledge regarding the structural relations of the veins and crossings.[3]

[1] Lindgren, W., "The Gold-quartz Veins of Nevada City and Grass Valley Districts, California," U. S. Geol. Surv., 17th Ann. Rep., Pt. II, pp. 13–28, 1896.

[2] Lindgren, W., *op. cit.*, pp. 1–262.

[3] Howe, Ernest, "The Gold Ores of Grass Valley, California," Econ. Geol., vol. 19, no. 7, 1924.

GENERAL GEOLOGY.

Areal Geology.—The general geology of the district has been fully treated by Lindgren.[4]

Summarized, the rocks of the Grass Valley area consist of a core of pre-Cretaceous granodiorite (or perhaps more properly, quartz-monzonite), flanked on each side by an older basic igneous complex consisting mostly of diabase, which is in turn bordered by younger Carboniferous slates, and all are in a dome-like structure of roughly ellipsoidal outline that owes its origin to the intrusion of the granodiorite core. Later (Neocene) volcanics, alluvials, and gravels form a superficial mantle of no significance in connection with the veins.

Petrography.—Of the country rocks, only the granodiorite will be further discussed, since the veins in depth lie almost wholly within it, and it is with the deep-level features of the deposits that this study is concerned.

Relatively fresh granodiorite from four crosscuts in different parts of the area and at various levels shows great uniformity of composition. It exhibits a typical granitic texture, and is grayish in color. Feldspar, quartz, and hornblende, with minor amounts of biotite, are the essential minerals of this rock.

In thin section, plagioclase is seen to be the predominant mineral, making up some 40 per cent. of the rock, with orthoclase, quartz and common green hornblende in about equal amounts of 15 to 20 per cent. Magnetite is a common accessory, and zircon was noted. Secondary leucoxene is present in relatively fresh rock, but much more commonly so in the altered walls of the veins. Lindgren mentions also primary titanite and apatite as accessory minerals, but these were not noted in this investigation.[5]

Alteration.—The granodiorite as it occurs near the veins and crossings has undergone alteration of varying degrees of intensity, and is observed to range from a state of relative freshness to a condition of metamorphism so complete that only slight traces of the original minerals remain.

In general, the first mineral to suffer alteration is amphibole,

[4] Lindgren, W., *op. cit.*, pp. 28–148.

[5] Lindgren, W., *op. cit.*, p. 42.

which is converted to chlorite with magnetite or pyrite, or less commonly to sericite. Leucoxene and limonite are common alteration products, the former indicating the presence of considerable titanium, probably largely as associated ilmenite.

Next in order of susceptibility come the plagioclases, which go to sericite or calcite, or to an aggregate mixture of both. Figs. 1 and 2 illustrate the process in its initial and final stages, respectively. Orthoclase is more resistant, but alters to sericite, in some cases completely.

Quartz may be altered to sericite, which replaces it along cracks and crystal borders, as shown in Fig. 2. In some cases there is strong evidence pointing to the nearly complete removal of quartz, for small residuary grains in sericitized granodiorite make up far less of the mass than is the case for fresh rock. Epidote is occasionally developed along cracks and minute seams in granodiorite.

Silicification of the wall rocks has not been observed. In a few cases, quartz of probable metasomatic origin is abundantly present in fragments of country rock included within the vein.

Pyrite is common in both hanging and foot walls, where it occurs as small perfect cubes of undoubted secondary origin, or as grains with chlorite from the alteration of hornblende. Arsenopyrite in small euhedral crystals is present, in places, in the wall rock.

Mechanical break-down of the fissure walls has greatly facilitated chemical change. Thus, in the more highly sheeted and crushed areas, rather intense alteration extends into the wall rock many feet beyond the vein; on the other hand, in the case of the tight crossings, relatively fresh granodiorite may be found a fraction of an inch from the fissure.

Commonly the thicker portions of the veins are characterized by a more intense and far reaching alteration of the walls, but the mineralogic nature of metamorphism has not been observed to bear any distinct relation to values in the adjacent vein.

Alteration has proceeded in the same fashion in the walls of both veins and crossings, with no mutually distinctive characteristics. The mineralogy is in both cases the same, and the degree to which changes have developed is largely dependent on mechanical causes.

Briefly, then, rock alteration in both vein and crossing walls has been essentially the same mineralogically, and may be very slight or very intense, dependent on the degree of crushing and

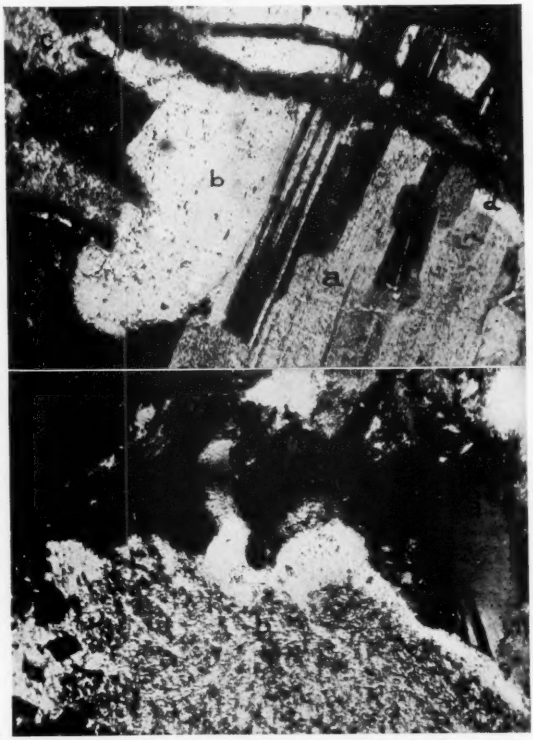

FIG. 1 (upper). Relatively fresh granodiorite, Empire, 6200 level. Twinned plagioclase (*a*); quartz slightly replaced at edges and cracks by sericite (*b*); sericite aggregate (*c*) and replacing quartz (*d*); chlorite and leucoxene (black, lower left); later stringer of chlorite, sericite, and leucoxene (across top). X-nicols, × 110.

FIG. 2 (lower). Highly altered granodiorite near vein, Empire, 7000 level. Shows ribbon extinction in quartz due to strain (*a*); plagioclase, thoroughly sericitized (*b*); chlorite with pyrite and leucoxene (upper left); secondary cubes of pyrite (left). X-nicols, × 110.

sheeting which has taken place, and to a less extent on the amount of fissure filling that has come in. Alteration products are chiefly sericite and calcite, with considerable chlorite and pyrite, and noticeable amounts of limonite, leucoxene, and indeterminate cloudy "mud," with at times arsenopyrite. The character of wall rock alteration is not distinctive for either veins or crossings.

THE VEINS AND CROSSINGS.

Structure.

Following the granodiorite intrusion two main systems of fissures were developed, in the granodiorite itself and also in the diabase. Of these, one has a general north-south strike, as exemplified by the Empire and Pennsylvania veins; the other system, with its roughly east-west trend, is represented by the North Star and New York Hill veins. The fissures of both systems commonly exhibit flat dips (25° to 30°), and may dip either way from the strike. As a rule, however, the strong veins of each system dip in a common direction, whereas those of opposite dip are weaker veins of relatively small extent.

It has been noted that the two vein systems are roughly parallel to the major and minor axes of the ellipsoidal intrusive, with the stronger or more persistent fissures parallel to the longer axis, and with the dips of the fissures showing a tendency to converge toward some central point.[6] All the veins exhibit local variations in dip and strike, but the general trend of both is remarkably constant for long distances. In the case of the Empire vein, mine workings have shown a single fissure to persist for many thousands of feet along both dip and strike. The more recent developments in depth have disclosed a marked steepening of some of the veins, a feature with which this study is considerably concerned, and this will be discussed presently in greater detail.

In addition to the flat-dipping vein fissures, other systems of nearly vertical fissuring intersect the veins at low angles with their strike (averaging 10° to 15°), and are known in the district as "crossings." They occur commonly as parallel breaks or zones of

[6] Lindgren, W., *op. cit.*, p. 170; Howe, Ernest, *op. cit.*, pp. 602–603.

sheeting, or as distinct single fissures. Some of them have suffered rather severe alteration of the walls, much of which may be attributed to shearing. Others are firm and tight, and little or no

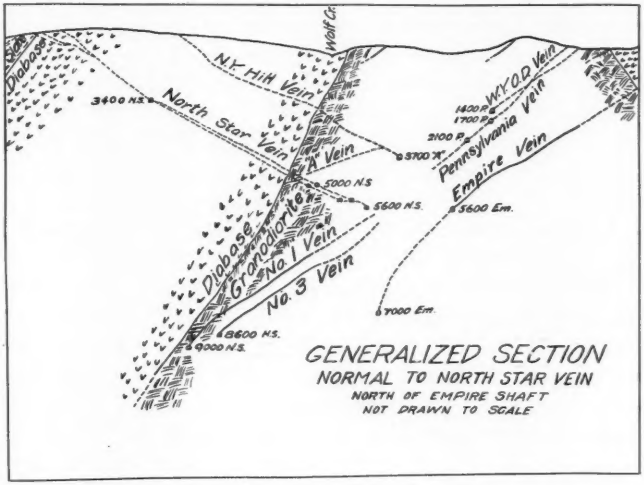

FIG. 3. Generalized section normal to North Star Vein, north of Empire Shaft.

alteration may be noted. Many of these fissures serve as conduits for the downward movement of water, and are called "water crossings."

In age, the vein fissures and crossings are probably broadly contemporaneous, although some believe the crossings to be distinctly older;[7] it is probable that their development started earlier, and overlapped that of the vein fissures. It is certain, at all events, that in places the veins are offset by the crossings, whereas in others the reverse is true; in all cases displacement has been slight. The most common effect of the crossings on the veins, so far as structure is concerned, is to cause a local deviation of dip and strike of the veins into the crossings, or, in some cases, a brooming out of the vein filling against the crossings.

[7] Howe, Ernest, *op. cit.*, p. 603.

The cause of fissuring is an interesting and moot question, discussion of which is limited by lack of space; suffice it to say that various strains set up as a result of the granodiorite intrusion are commonly regarded as primarily responsible. It has been suggested that the presence of considerable masses of serpentine to the north and east, formed as they are with a large increase in volume, may have had considerable effect in producing strains in the adjacent diabase and granodiorite.[8]

In the present lower levels of the Empire mine, in the region of one of the main crossing zones, the vein has steepened markedly, in places to a dip of 60° or 70°, and has lost much of the characteristic persistence of strike that is so remarkable a feature in its upper parts, in favor of an *en echelon* arrangement.

The deep main crossings are regarded by some as the major control of fissuring, the flat veins having resulted from decreased pressure and consequent relief of strain nearer the surface. The steepening of the Empire vein into a main crossing is significant in this connection; it may indicate the region where pressure conditions changed sufficiently to permit formation of the flat fissures.

Deposition of Fissure Filling.

The Veins.—Subsequent to the deformation that created the fissures, but quite possibly before all movement had ceased, began the deposition of quartz, accompanied by some carbonate and pyrite. The manner in which this process was carried out is of great interest, and has been explained by means of at least three theories, as well as by a combination of two. It is not the purpose of this study to attempt an explanation of the origin of the veins, but since in the course of the work certain observations and notes were made which bear directly on the question, they will be presented and briefly discussed. A summarized statement of the theories that have been advanced is in order, and an outline of them is, therefore, given below.

1. Deposition in pre-existing cavities through the agency of dilute thermal solutions, containing carbonates, silica, hydrogen or sodium sulphides, and some gold and metallic sulphides, is the

[8] Nobs, F. W., personal communication.

explanation offered by Lindgren.[9] He states that no evidence of silicification of the walls has been encountered, but that they have been extensively sericitized and carbonatized. He cites the existence of vugs and of perfectly crystallized quartz in a carbonate matrix as evidence in support of his theory. He states that the occurrence of quartz in stringers ramifying through the adjacent walls and the fragments within the vein are not conclusive evidence of replacement, since carbon dioxide and hydrogen sulphide may have corroded the country rock originally, creating openings that were filled with silica passively deposited from solution.

2. Deposition by replacement of the country rock by silica, along with carbonate and sulphides, carried upward in solution through the pre-existing fissures, is the explanation put forward by Howe.[10] He states, in effect, that solutions percolating upward through the fissures and zones of brecciated material carried compounds that actively attacked and replaced the rock, but especially the more easily invaded crushed material that lay within the vein walls. He cites the occasional thickness of the veins in excess of conceivable open spaces, the ramifying stringers, and the skeletal remnants of included fragments in various stages of replacement, as strong supporting evidence. He concedes the occasional existence of small cavities to account for the vugs.

3. Spurr explains these veins, along with all others of their general type, as due to magmatic injection in the form of dikes, or veindikes.[11] He believes the replacement of included fragments to have taken place within the injected magma as a process of minor importance to the general dike-like injection, and states that "lack of silicification of the walls of California quartz veins surely denotes a dry ore magma."[12]

4. Lindgren has later conceded that there has been replacement, but refuses to repudiate cavity-filling as an important, if not the dominant, cause.[13]

[9] Lindgren, W., *op. cit.*, p. 182; Lindgren, W., "Characteristic Features of California Gold Quartz Veins," *Bull. Geol. Soc. Amer.*, vol. 6, pp. 229–233, 1895.

[10] Howe, Ernest, *op. cit.*, pp. 614–619.

[11] Spurr, J. E., "The Ore Magmas," vol. 2, pp. 725–727; Spurr, J. E., discussion of paper by Howe, *op. cit.*, p. 621.

[12] Spurr, J. E., *op. cit.*, p. 727.

[13] Lindgren, W., discussion of paper by Howe, *op. cit.*, p. 620.

Later introduction of the gold with galena and sphalerite along crush zones, formed in the quartz and pyrite subsequent to original deposition of these gangue minerals, is recognized by Howe, but he makes no attempt to explain the mode of its introduction other than to say it came in later, and was precipitated by pyrite in the crushed areas.[14]

Spurr, on the other hand, concludes that the later injection of gold is due to its being the final differentiate of the ore magma.[15]

The following observations may throw some additional light on the question.

1. In a few slides, secondary silica was observed to be replacing, or to have nearly completely replaced, small fragments of country rock that lay within the vein, a fact that might be cited in support of Howe's theory. In each of these cases, the quartz is in the form of a fine aggregate of anhedral grains. On the other hand, in every section examined in which the quartz is without question primary vein material, it is very coarse-grained, and displays either interlocking anhedral structure, comb, or columnar to roughly euhedral-prismatic structure (Fig. 1). Comb and euhedral-prismatic structures are strong indications of deposition in open space.

If the vein quartz came in largely by replacement, as Howe affirms, why does it not exhibit the same structure as the quartz in the few silicified inclusions with which it is in contact? It seems logical that these inclusions might be explained as due to local replacement, of secondary importance to the precipitation (or freezing) of the main vein mass. On the other hand, many contacts of stringer quartz with sericitized or carbonatized country rock are seen in thin section to be irregular, with the stringer quartz penetrating the altered wall rock for short distances, and containing small inclusions of it near the contacts. This is a microscopic duplication of a feature of the veins commonly observed on a much larger scale.

In other cases, penetration of the walls by small stringers is conspicuously lacking, and the quartz and country rock are in sharp contact.

[14] Howe, Ernest, *op. cit.*, p. 607.

[15] Spurr, J. E., discussion of paper by Howe, *op. cit.*, p. 621.

2. Fluid inclusions, or vacuoles, are abundantly present in the fissure quartz. In those cases where the quartz penetrates the wall rock, the fluid inclusions commonly are roughly streaked or banded in a direction normal to the walls; in the cases of sharp contact the inclusions may be banded more or less parallel to the walls, and are in other cases without marked arrangement. The banding parallel to the walls gives the impression of deposition by precipitation or freezing from a solution or viscous mass in slow motion. This idea is strengthened by the absence of well formed crystal outlines in such cases.

3. Zoning by impurities or fluid inclusions arranged in crystallographic directions is common in the vein quartz (as shown rather poorly in Fig. 5), and was noted also in carbonate. In quartz, this was variously observed to be parallel to both prism and pyramidal terminal faces. Where abundantly present, inclusion zoning would seem strong evidence against the replacement theory, from the following considerations:

Most of the thin sections were cut approximately normal to the vein walls; in many such sections, zoned quartz showing the outline of the hexagonal "plan" section of the crystal was noted. This zoning means that under certain conditions a crystal core was deposited; as conditions changed, deposition went on with the inclusion of a greater or less quantity of impurities or fluid bubbles, as the case might be, as a zonal fringe. Not only is this seen in the hexagonal "plan," but in the same section, zoning in both "plan" and "vertical section" through prism and pyramid, are present in close proximity, giving the appearance of a series of successively larger crystal shells nested together. This phenomenon can only mean that deposition proceeded simultaneously in many directions from central nuclei, a condition controversial to the idea of quartz growing by replacing its way into the country rock in one or two directions.

4. The occurrence of perfectly terminated euhedral quartz, oriented at random in a matrix of carbonate, should be regarded as proof that deposition was by crystallization from a solution of greater or less viscosity. Figs. 5 and 7 illustrate this condition. This class of material is by no means uncommon, especially in the

North Star mine; it is quite characteristic of certain parts of the No. 3 vein.

5. The occurrence of sericite in the vein quartz was frequently noted. In many instances it is present in small isolated flakes and bunches, which might lead to the inference that it represents material residual from replaced rock. On the other hand, in many cases these bunches are closely associated with small stringers of the same material that crosscut the quartz regardless of grain boundaries, and are distinctly later than the quartz. Furthermore, the isolated bunches are similar in occurrence to later sericite in the original quartz grains of the adjacent wall rocks, except that in the latter case the sericite is commonly much more abundant (Fig. 2). Thus, the point is raised that if all the sericite or sericite-calcite aggregates are later than the quartz of the veins, the replacement theory is still further weakened.

The writer is inclined to the belief that, in general, precipitation in open space was the dominant means of vein formation, but that some replacement also took place. A combination of the two phenomena is conceivable, and it is therefore believed, in agreement with the later contention of Lindgren, that filling took place where open space already existed or was created at the time by slight movement or great hydrostatic pressure; and that where the fissures remained relatively tight, some form of replacement was operative. The question of relative importance of the two types of deposition reverts to the classic contention concerning the existence and size of open spaces in depth.

The occasional thickness of the quartz veins in excess of conceivable open space cannot, however, be taken as decisive evidence of replacement. Commonly quartz, from such thick areas, exhibits in thin section all the typical structures of open-space deposition. The presence of bands and partings of chlorite and sericite, and the anomalous behavior of the quartz (indicating great strain), suggest that the fissures may have been frequently reopened by intermittent movement; in this way veins may attain great thickness even though large open cavities never exist at any one time.

The Crossings.—The vertical fissures, or crossings, are com-

monly barren of mineral filling; in many cases they carry small amounts of iron oxide and indeterminate fine "mud" gained from downward movement of water; but in most instances they are filled with more or less true vein material such as carbonate, quartz, and minor amounts of sulphides.

Where mineralized, it is probable that the crossings owe their content of gangue and meager metallic minerals to the same general source as do the veins. In age, these deposits must be roughly contemporaneous with the veins, for they may cut across the veins without interruption, or be cut off completely by them. Faulting cannot be cited as a reason for this last condition, for crossings so terminated have been observed in close proximity to pre-mineral dikes, either undisturbed, or at most offset only a foot or two.

The meager mineral content of the crossings relative to the veins is not believed to be due to a difference in source of mineralizing solutions or to a large age discrepancy, although the observed fact that crossings as a rule contain much more carbonate, relative to the veins, would indicate an overlap in geologic age between the two occurrences.

Crossings are more commonly than veins characterized by a sharp contact with the walls. If this is an indication of cavity filling, then it is conceivable that the crossing deposits might owe their small thickness to the failure of replacement processes to enlarge the cavities; the existence of open spaces of a magnitude comparable to the thickness of filling in many crossings is common enough.

CHARACTER OF FISSURE FILLING.

Mineralogy of the Veins and Crossings.

The veins are characterized, in general, by predominant quartz, along with variable quantities of carbonate and metallic minerals, chiefly pyrite. In barren areas, however, carbonates may comprise a large proportion of the vein matter, with sulphides practically absent. Intercrystallized carbonate and euhedral quartz in all proportionate amounts have been noted in different places (Figs. 4–7), the occurrence on the 7500 level of the No. 3 vein

FIG. 4 (upper). Vein quartz, Empire, 1300 level. Interlocking prismatic structure, with fluid inclusions cut off by phantom veinlet and by later quartz (*a*); host structure in quartz (*b*); chlorite stringer (*c*). No opaque minerals present. X-nicols, × 28.

FIG. 5 (lower). Vein quartz, Empire, 3400 level. Euhedral quartz with carbonates in the interstitial spaces; inclusion zoning in quartz crystals; crush zone, with pyrite, carbonate and sericite (*a*); sericite attacking quartz at borders and along cracks (*s*). X-nicols, × 28.

being noteworthy. Here quartz crystals up to two inches long, of slender cross-section, are heterogeneously scattered throughout a matrix of carbonate in a strong ledge over a foot and one-half wide. In good ore, the quartz is usually massive macroscopically, carbonate is present in minor amounts, and sulphides make up from 1 to 4 or 5 per cent. of the vein filling. Nearly all good quartz is milky white in color.

With a few exceptions, what may be said concerning the minerals of the veins will apply in general to the crossings as well. The same non-metallic gangue minerals are present, but with the relative abundance of quartz and carbonates reversed. Certain minerals found in the veins are absent from the crossings, and vice-versa, but these minerals are of minor importance in either case. The physical characteristics of crossing minerals are similar to those of material in the small veins.

For the sake of clearness and brevity, the more common minerals will be described individually.

Quartz, as stated above, is the most important gangue mineral. In hand specimens, it appears either massive granular, or with well formed crystal outlines in a carbonate matrix. Faceted crystals lining small vugs are not uncommon. Under the microscope the vein quartz usually appears as a massive intergrowth of coarse anhedral grains, or as interlocking columns and crude prisms, often with a little carbonate filling the left-over spaces (Fig. 4). Comb structure is often encountered, especially near vugs or in small veins and large stringers.

Inclusions in the form of minute impurities and fluid bubbles or vacuoles are nearly always present in greater or less amount (Figs. 4, 5); these are arranged in various ways, such as banding parallel to vein walls, radially from pyrite or other quartz grains, and in irregular bunches. Crystal zoning by arrangement of inclusions along crystallographic directions is common (Fig. 5). Also, in some places no arrangement is seen, but rather the inclusions are heterogeneously scattered throughout the mass.

Phantom veinlets, or bands of clear quartz that intersect large grains irrespective of boundaries, and cut off the inclusions (Fig.

4), but which extinguish perfectly at the same time as the host crystals, are common.[16] This structure represents a later deposition along cracks, in crystallographic orientation with the intersected quartz, by a solution or magma that contained little or no gaseous material. Probably it represents quartz of a final stage of the original deposition period.

More or less crushing and rearrangement is nearly universal; in some cases restricted crush zones comprise only a small part of the mass, in others, nearly the entire width of the vein has been subject to failure under strain. Granulation and recrystallization, the development of small secondary crystals within larger ones (host structure), and anomalous behavior under crossed nicols (wavy or undulous extinction, ribbon structure due to shear), are all common features characteristic of crushing or great strain (Fig. 7).

Quartz occurs in crossings in amounts usually subordinate to carbonate, but showing the same features as in the veins, including later crushing and rearrangement.

Carbonate is second only to quartz in abundance in the veins, and in barren areas may exceed it. It is usually of a milky white appearance, and in such cases is probably rather pure lime carbonate; quite commonly, however, it is reddish brown to pink in color, due to impurities (in which case it is cloudy in thin section) or to isomorphous mixture with iron carbonate. The frequent presence of the carbonates of iron and magnesium is indicated microscopically by curved cleavage.

Carbonate is commonly well crystallized, and in veins occurs sometimes in cleavable masses more than a foot across. Twinning is a common phenomenon (Fig. 6). Where intergrown with quartz, the cleavage rarely fails, but it commonly shows no crystalline structure in its usual occurrence as secondary stringers, flakes, and aggregate masses (in which sericite is a common associate). Terminated crystals are found in vugs, commonly with scalenohedron faces.

[16] The term "phantom veinlets" is borrowed from Adams, Sidney F., "A Microscopic Study of Vein Quartz," Stanford University thesis for Master's degree, June, 1920.

FIG. 6 (upper). Barren vein material, Empire, 3000 level south. Cloudy carbonate (*c*) (probably calcite), showing twinning and well developed cleavage; quartz (*q*) in irregular grains and euhedral crystals. One nicol, × 28.

FIG. 7 (lower). Vein material, Empire, 7000 level north. Coarse anhedral to prismatic quartz, with ribbon structure under x-nicols due to strain (*q* 1); small euhedral quartz crystals and crushed pyrite in carbonate (*q* 2); large pyrite crystal (black, left) with fringe of later quartz which does not show strain; undulous extinction in carbonate. X-nicols, × 110.

Inclusion zoning is less common than in quartz, but has been noted; in one slide phantom veinlets are present in carbonate, but may be due to a similar structure in quartz that the former has replaced. Wavy extinction due to strain is very common (Fig. 7).

In crossings, carbonate is very abundant, both as the pure mineral calcite and in isomorphous combination with magnesium and iron carbonates. It displays all the characteristics of vein carbonate in thin section, but large cleavable masses are not encountered, due to the small width of most crossings. Secondary carbonate in dense aggregates and thin seams is abundant in crossings.

Sericite occurs in veins and crossings as small secondary bunches, flakes, and stringers replacing quartz and carbonate. In many instances there can be no doubt of its later origin than these minerals, for it may be seen in cracks and replacing other minerals along grain borders; in other cases the relations are not so well defined, and it might conceivably be regarded as a residual from altered country rock that the quartz or carbonate has replaced. Sericite is commonly in beautiful foils with a finely felted structure, as well as in dense aggregates, alone or with calcite or fine-grained quartz. Its presence in vein quartz may often go unsuspected until the material is examined in thin section. It is a common constituent of the gouge parting at vein walls.

Chlorite occurs in thin seams and bands, and with sericite is commonly the mineral responsible for the sheeted or banded appearance of the veins. It is common in gouge.

Gold, the principal metal in the ore, occurs as a rule in intimate association with pyrite, galena, or sphalerite, but occasionally free in quartz; it possesses an average fineness of about 857.[17] It is generally invisible to the eye, but occasional spectacular specimens are found that show abundant gold. Where free in quartz, it has a dendritic or wire structure, due to growth between quartz grains

[17] Amalgamated gold is well over 850 fine, but that precipitated from the cyanided concentrates has more silver, probably due to the presence of silver minerals with the other sulphides.

and in cracks. In pyrite it is in blebs or cracks, but with galena and sphalerite it occurs in intimate contemporaneous association.

Gold in workable quantity is confined to the quartz veins and stringers, although it was noted from several crossings, where it is similar in occurrence to vein gold, except that pyrite is less commonly associated with it, and galena and blende are more so.

Pyrite is the principal sulphide mineral of the veins, but rarely accounts for over 4 or 5 per cent. of the ore, and is usually even less abundant. It is commonly noted as primary cubic crystals in quartz that may be more or less crushed and dragged. It is practically always a constituent of good ore, and forms the chief indicator of pay rock. Massive pyrite is common.

TABLE I.

Mineral.	Veins.	Crossings.
Quartz	Chief mineral.	Common.
Calcite (Carbonates)	Common, especially in lean areas.	Chief mineral.
Sericite	Universal also in gouge and partings.	Common, in gouge, etc.
Chlorite	Common, seams and gouge.	Common, seams and gouge.
Leucoxene	With chlorite and sericite.	In chains and specks, and with chlorite.
Limonite	Stains, and with leucoxene.	In seams and stains.
Chalcedony	In ore-shoots in upper levels, stringers or radial aggregates.	Not noted.
Scheelite	Reported.	Not noted.
Epidote	Not noted; may be present.	In aggregates of lath-shaped crystals, common in some crossings.
Gold	With pyrite, galena or blende, sometimes free in quartz.	May occur with galena or blende.
Silver	With gold; possibly with galena and rare tellurides. Never free.	Probably with gold; no determinations made.
Pyrite	Common in veins and altered walls.	Common, often a later mineral. In walls.
Galena	Less common than pyrite. Usually later, in crush zones; closely associated with gold. Often coated with alteration products.	A later mineral in crush zones. Gold when it occurs is associated with it.
Sphalerite	Less common than galena; probably late. Gold often associated with it.	About as common as galena; late. Gold associated with it when present.
Arsenopyrite	In high-grade ore.	Not noted; may occur.
Pyrrhotite	Locally common.	Not noted; may occur.
Chalcopyrite	Rare, with other sulphides.	Massive, common in two crossings, with epidote.
Tellurides	Reported.	Not reported.
Cinnabar	Not noted.	Minor amounts, one crossing.
Hematite	Not noted.	More or less crystallized in flakes, two crossings; as seams or partings, slickensided, between carbonate stringers.

Pyrite is quite common in crossings, usually as a later mineral; in this respect its occurrence is somewhat distinct from the pyrite of the veins, which is mostly primary. Crossing pyrite shows irregular structure around and through grains in crush areas.

Table I will serve to enumerate all the minerals found in the veins and crossings, including those just described, with the exception of certain rare species that have been described from the district but were not observed in this study.

Paragenesis of Vein Minerals.

The original vein filling in typical occurrences consists of coarse quartz, with more or less carbonate and a little pyrite. That the carbonate deposition apparently overlapped quartz somewhat is probable, for in crystal intergrowths of the two, the quartz is well developed with carbonate filling the spaces; furthermore, slight encroachment by carbonate on quartz borders was commonly seen. Pyrite may have crystallized slightly ahead of quartz, for the latter is commonly oriented roughly around it.

One or more periods of crushing broke down the coarse quartz and pyrite, giving access to later solutions; these deposited galena, sphalerite and gold, in cracks in the pyrite and quartz. The gold is commonly closely associated with the galena and sphalerite, and it is difficult to assert that it is different from them in age; sphalerite is a little later than galena, which indicates that deposition of gold continued longer than that of galena, and well into the sphalerite period.

Some carbonate and quartz came in with the gold and sulphides. The crush areas contain much sericite and chlorite, but their age relation to metallic deposition is obscure. However, it is probable that much of the sericite and chlorite of the veins was deposited by the gold-bearing solutions.

That most of the gold is later than the original quartz and pyrite is a well established fact. Nevertheless, the occasional presence of free gold in quartz, unaccompanied by other metallic minerals, and in areas where there has been no marked crushing of the quartz, leads to the belief that some of the gold may have come in

with the original quartz. In most cases, however, the relations clearly point to later origin of the gold. Such features as filling along cracks in pyrite, with the parallel walls of the cracks undisturbed; dendritic growth around and between crushed quartz grains; and cross-cutting deposition in cracked quartz, afford indisputable evidence in support of this view. Bain has recently demonstrated a similar condition for Ontario gold ores.[18]

The arsenopyrite is probably of an age similar to original pyrite.

Chlorite and sericite may be in some cases even earlier than the primary quartz, but are commonly if not usually definitely later.

Paragenetic relations of the less common vein minerals are not clear.

Paragenesis of the Crossing Minerals.

Quartz and carbonate, with some pyrite, formed the primary filling in crossings; relative to the veins, primary pyrite is far less abundant and carbonate much more so.

As in the veins, later crushing permitted the ingress of mineralizing solutions carrying sulphides and gold. Pyrite, galena, and sphalerite were deposited in the crush areas, in the order named. Gold accompanied all three, as did some quartz, sericite and carbonate, but it is most closely associated with the galena and blende. The sulphides and gold were thrown down in cracks and interstitial spaces, but effected more or less replacement of the gangue as well. Auriferous mineralization is, in general, very lean.

The genetic relations of hematite, cinnabar, and chalcopyrite were not clearly ascertained, since their rarity rendered them relatively unimportant in view of the limited time available for the work.

Much carbonate, sericite, and chlorite, and some leucoxene, were deposited as secondary or later minerals, especially in zones of crushing and strain. Their age relations to the ore minerals are not wholly understood; they are usually closely associated with metallic mineralization.

In general, the crossing material was deposited in a manner similar to that of the veins, with certain differences in relative

[18] Bain, Geo. W., "Microscopic Structure of Ontario Gold Quartz." Original manuscript; subsequently published in *Trans. A. I. M. E.*, Tech. Pub. No. 327, 1930.

abundance of the component minerals. These differences are not great when crossings are compared to lean or barren portions of veins.

DISCUSSION AND CONCLUSIONS.

Mineralogic Comparison of Veins and Crossings.—A marked similarity exists between the major minerals of the veins and the dominant species of the crossings. Quartz, carbonate, sericite, sulphides and gold are present in both. Where quartz predominates over carbonate, and metallic minerals are measurably present, ore is the result. This condition obtains in veins over widths great enough to insure profitable working; it is not lacking in the vertical crossings, but in these cases the filling is nearly always of insufficient thickness to pay the cost of extraction. Microscopically, there is no positive means of distinguishing the one type from the other, and, in fact, no real difference exists. Physical causes, probably involving the attitude of the fissures among other things, are believed solely responsible for the relative weakness of the crossings, as far as metallic mineralization is concerned.

A more common type of crossing than that just described is characterized by dominant carbonate, with minor quartz and abundant sericite and chlorite in seams and stringers. Pyrite may be present, but other sulphides and gold are conspicuous by their absence. Naturally, this typical crossing occurrence is readily distinguishable from the strong quartz veins, but nevertheless exhibits a striking similarity in mineral content to the weak barren portions of the veins.

The weak veins, like the typical crossings, may carry much carbonate, considerable sericite, and chlorite, with only minor quartz and sulphides. In those places where they have assumed a steep dip, their similarity to crossings is marked. Other weak portions of the veins may contain considerable quartz in thin, flat lenses.

The few occurrences in crossings of such minerals as epidote, hematite and cinnabar can be of no practical value, either because of their local and restricted distribution, or because the similarity of conditions in veins and crossings makes it difficult to believe that their presence in the one case and absence in the other can be infallibly relied upon.

These conditions are unfortunate, for a means of distinction between crossings and weak veins, especially the veins that are steeply inclined in the lower levels, would be a valuable tool in planning and conducting development.

Micro-structural Comparison of Veins and Crossings.—The structural features of the various minerals of veins and crossings, as seen in thin section, have been rather fully described. Little need be added, save that concerning the filling material as an aggregate whole, strain and crushing are rather more predominant along pre-existing zones of weakness such as grain or crystal borders, phantom veinlets in quartz, contacts between minerals of different hardness, and so on. Furthermore, where crushing has been severe, the hard brittle minerals apparently localize the strains and fail first. Thus, failure in a quartz-calcite-pyrite mass starts with strain and then crushing in the quartz; pyrite is next affected, usually by a crushing of the borders and production of a network of cracks throughout the mass, but also not infrequently by a complete break-down and dragging of the fragments; and last to fail is calcite, the softest mineral of the three.

In comparing veins and crossings, it is clearly apparent that the same types of micro-structures have been produced in each; the features peculiar to individual minerals, such as phantom veinlets, inclusion zoning, or coarse prismatic structure in quartz, are noted alike in both cases. Likewise, crushing and strain phenomena are similar. For the comparative case of barren veins versus crossings, it is doubtful if any micro-structural means whatever exists for distinguishing the one from the other.

Conclusions.—Crossings and veins possess many common characteristics, as examined under the microscope; mineralogically they are essentially the same, and their respective micro-structures are practically identical. Strong veins present features so distinctive in the underground workings, and usually also in hand specimens, that microscopic methods for their differentiation from crossings are superfluous. although it should be noted that even strong veins are usually not distinguishable in thin section from quartz-bearing crossings when only gangue minerals are present. The logical field for the application of petrographic methods to the problem

is in the region of lean or barren fissures of steep dip, such as occur in the lower levels of the Empire mine.

Unfortunately, this study has shown that neither lean veins nor crossings possess characteristic petrographical or micro-structural features so distinctive or peculiar to themselves as to constitute definite criteria for differentiation. In fact, the leaner a vein becomes, the more striking microscopic resemblance it bears to the typical crossings. The few features peculiar to the one occurrence or to the other are of a sporadic nature, and are unreliable.

Wall rock characteristics are of no service in attacking this problem. The degree of alteration is dependent on the amount of mechanical deformation, and perhaps to a less extent on the quantity of material introduced into the fissures. These features may be identical for a vein and for a crossing of like magnitude.

In conclusion, it must be said that this investigation has been productive only of negative results. However, it is hoped that the information secured may prove of some value in gaining a greater understanding of the veins and crossings.

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WASHINGTON, D. C.

THE GEOLOGY AND ORE DEPOSITS OF BUCHANS, NEWFOUNDLAND.

W. H. NEWHOUSE.

THE history of the finding and winning of ore at Buchans is unique. Here, for the first time in North America, a large ore body was found by geophysical prospecting and the commercial exploitation of the ores has been rendered possible by the relatively new methods of selective flotation. The resourcefulness and initiative displayed in the enterprise show well those qualities necessary for successful development and management of modern mining business.

The history of the discovery of the ore bodies and some discussion of the geology has been given elsewhere.[1]

The work on which the present paper is based was done during the summers of 1927, 1928, and 1929. M. J. Buerger and A. C. Abbott gave much assistance in the field work during 1928. Much help was given by members of the mine staff at Buchans and by the individuals of the Swedish American Prospecting Corporation. Thanks are due to the officials of the American Smelting & Refining Company for permission to publish this article.

The town of Buchans is located about five miles northwest of Red Indian Lake in Central Newfoundland. It is about twenty-eight miles from the main line of the Newfoundland Government Railroad, with which it is connected by a branch railroad.

TOPOGRAPHY.

In the vicinity of Buchans, low rolling hills relieve the monotony of flat "muskeg" marshes dotted with numerous small lakes. Any slight rise in the land is commonly covered by a dense growth

[1] Lundberg, H., "Recent Results in Electrical Prospecting for Ore": Volume on Geophysical Prospecting, *Amer. Inst. Min. & Met. Eng.*, pp. 118–122, 1929. Snelgrove, A. K., "The Geology of the Central Mineral Belt of Newfoundland," *Canad. Min. & Met. Bull.* 197, pp. 1057–1127, 1928.

of fir and spruce. A few miles to the north and west, intrusions of granite and diabase have been dissected to form a more rugged topography with hills several hundred or more feet high. The diabase hills are generally forest-covered, and the granite hills are bare.

In the vicinity of Buchans, and to the south and east, the topography is controlled by low ridges parallel to the strike of the lavas, volcanic breccias and tuffs, the ridges being largely massive lava flows and flow breccias, the tuff beds in general not resisting erosion so well and forming the valleys.

The streams have formed valleys transverse to the strike of the rocks. These major features of the topography were undoubtedly brought into relief by erosion before the last invasion of ice in Pleistocene time. Twenhofel[2] has suggested that the hills are remnants of a Cretaceous peneplain.

In the Buchans map-area two movements of ice are recorded by glacial striae and other evidence. The first, with movement from the northeast toward the southwest; the second, from slightly west of north, toward the southeast. The latter glacier was apparently only a tongue a few miles broad. Where the two different sets of striae are shown on the same outcrop, no difference in degree of weathering can be observed. It is, therefore, assumed that the one ice movement followed the other closely in time, and in fact may well have been a later phase of movement from a migrating center of ice accumulation on the height of land north and northeast of Buchans. No trace of Coleman's[3] early glacial period with strongly weathered outcrops and debris was found. Varved clays are found along the middle branch of Buchans Rivers.

GENERAL GEOLOGY.

The rocks in the vicinity of Buchans may be divided into three groups. The oldest group consists of lavas, flow breccias, and tuffs, which range from basaltic to rhyolitic in composition, the

[2] Twenhofel, W. H., "Physiography of Newfoundland," *Amer. Jour. Sci.* (4) 33, pp. 1–24, 1912.

[3] Coleman, A. P., "The Pleistocene of Newfoundland," *Jour. Geol.*, 34, pp. 193–223, 1926.

majority being andesitic. This group of rocks is termed the Buchans Series. These have been intruded by diabase, granite, and rhyolite porphyry. Later than these, and overlying part of them, is a series of sedimentary rocks of Carboniferous age.

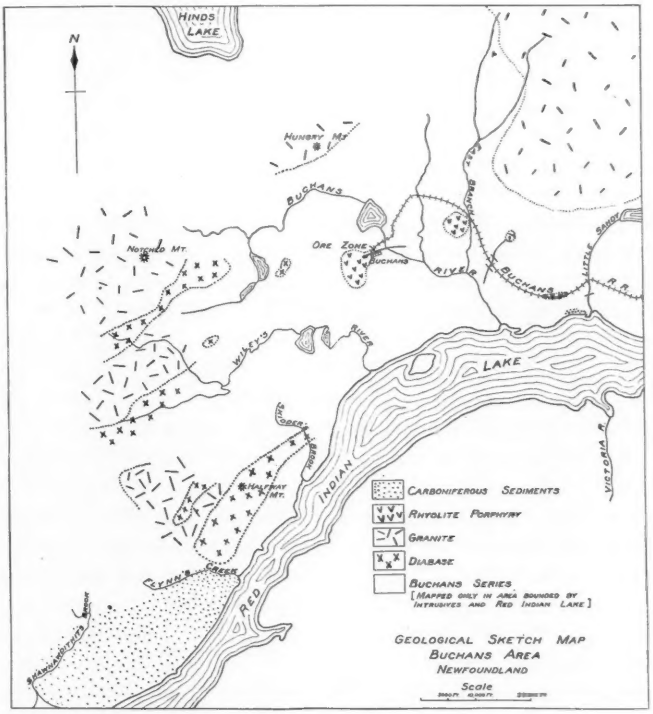


FIG. 1. Geological sketch map of Buchans Area.

Buchans Series.—Although the structure is complex and there has been some folding and faulting, the Buchans Series of rocks in general dip northwest and strike northeast. It will be shown later that the town of Buchans is on a broad bend in this prevailing structure. Between the town of Buchans and Red Indian

Lake the lava flows and breccias are andesitic to basaltic in composition; the lavas occasionally show pillow structure.

One section of tuff beds, arkose, and agglomerate passes through the town while another is found northwest of the town along Buchans River, the same section of rocks probably being represented along Little Sandy River, some seven miles east of Buchans.

North of these near the granite intrusions some rhyolite flows and breccias are found. In a general way this section of rocks is similar to the sections of Middle Ordovician and older rocks that are found along their northeast strike direction, some seventy miles away, near the mouth of Exploits River in Notre Dame Bay.[4]

The section differs in that shale and large amounts of chert and jasper are not found in the Buchans area. Until more information is at hand, however, the Buchans Series may tentatively be considered of Cambro-Ordovician Age.

In composition, the basalts and some of the andesites contain augite, but olivine is practically absent; chlorite, calcite and some epidote are widespread alteration products. Dacite is locally present. Rhyolite forming flow breccias may show some phenocrysts, with a microcrystalline groundmass, but where good flow-banding is present, few phenocrysts are found. The arkose is made up principally of quartz and feldspar grains with, in places, numerous rounded or subangular pebbles of granite, rhyolite porphyry, and some few fragments of andesitic rock and greenstone. It is obvious from the composition of the arkose that older granitic rocks occur on the island. In places the arkose resembles rhyolite porphyry so closely that it is difficult to distinguish between the two. The frequent presence of cognate zenoliths in the rhyolite porphyry tends to emphasize the difficulty.

The tuffs show in places fragments of feldspar and of chloritized ferromagnesian minerals. They commonly show banding which testifies to their sedimentary origin. These dark green tuffs are andesitic in composition, but those that display fine banding are light gray in color and quite siliceous, or cherty with occasional concretionary or nodular chert masses.

[4] Sampson, Edward, "The Ferruginous Chert Formations of Notre Dame Bay, Newfoundland," *Jour. Geol.*, 31, pp. 571–598, 1923.

An unusual type of sedimentary rock in the Buchans map-area is found near the shore of Red Indian Lake along Skidders Brook. At this place well-banded white and green chert with jasper, probably several hundred feet in thickness, is found. The occurrence is similar to that described by Sampson at Notre Dame Bay, although no Radiolaria were found in sections of the Buchans rocks.

Intrusives.—The age of the intrusive igneous rocks is pre-Carboniferous. Since the granites of Nova Scotia are Devonian in age, it may well be that the intrusive rocks, or at least the granites, in the Buchans map-area, belong to this same period of intrusion.

The sequence of intrusion is clearly diabase first, then granite, and rhyolite porphyry, with later diabase dikes. The intrusions are elongated parallel to the general regional strike of the older series of rocks. A large batholith some miles across is found in the northwestern part of the Buchans map-area, and another east of Hinds Lake, north of the map-area.

Northeast of Buchans, the older rocks curve in strike around the granite intrusion. West of Buchans, the older rocks strike, in the exposures nearest the intrusives, directly into the intrusives. It seems likely that the intrusions have been in part sill or laccolithic in nature and in part more transgressive.

Diabase.—The rocks mapped as diabase are fine to medium in grain size, and have ophitic texture. Labradorite and augite are the dominant minerals, although in places the feldspar is andesine. Accessory minerals are magnetite and apatite. Fragments of this rock in the granite commonly show transitions to a much lighter color.

The diabase has been chloritized thoroughly in some outcrops, and to a lesser degree in practically all of them.

Granite.—The granite is in large part massive with locally a gneissic structure. It varies from white or light gray to reddish in color, and from fine to medium-coarse in texture.

The minerals present are orthoclase, microcline, albite, perthite and a little oligoclase, feldspar.[5] Some examples show about half

[5] Determined by indices in immersion liquids and other optical data.

of the feldspar to be albite. It is thus seen that these rocks are granites that may locally approach quartz monzonite in composition. Quartz is an important constituent of the rock. Either biotite or hornblende may be present.

At one locality a red granite high in orthoclase feldspar intrudes a gray gneissic granite.

Rhyolite Porphyry.—All gradations appear to exist between rhyolite porphyry that contains small phenocrysts of quartz or feldspar or both, set in a cryptocrystalline groundmass, and coarser-grained varieties with similar minerals, of granophyric or granitic texture. The latter are in general found nearer the granite outcrops than are the fine-grained ones. This fact and the mineral composition, which is like that of the granites, certainly link them with the granites in origin.

Pyrite is commonly present in the porphyry but close inspection shows that it is mostly related to fractures. Apatite is a common accessory.

The main variety of porphyry found at the Lucky Strike ore body consists of scattered quartz phenocrysts set in a cryptocrystalline matrix. The rock is commonly reddish or gray on fresh fracture and weathers gray to white. Where fresh peat is stripped off it in the muskeg bogs, it is usually dead white in color due to kaolinization on the surface. This kaolinization has doubtless been caused by the acid peat water, a well known phenomenon.

The intrusions are both sill-like and cross-cutting in character. They are commonly to be measured in tens of feet rather than in hundreds, although the mass at the Lucky Strike ore body is over several hundred feet in thickness. No rhyolite porphyry intrusions were found in the granite within the area examined.

Later Diabase Dikes.—These diabase dikes are clearly later than the other rocks described. They cut rocks of the Buchans Series granite, rhyolite porphyry, and the ore, and show distinctly chilled margins. Adjacent to the ore body at Lucky Strike, one of these dikes does not show the pronounced fracturing and shearing found in the rocks on both sides of it. Strong shear planes at approximately right angles to it stop abruptly at its contact as

does also mineralization in its wall rocks. The diabase dike is evidently later than the ore.

It presents, in general, the freshest rock in thin sections of any in the Buchans map-area. Ordinarily the texture is ophitic, the minerals being labradorite and augite, with small amounts of magnetite and apatite. Even in the small dikes of twelve to fifteen feet in width, it is more coarse-grained than the older diabase that forms large masses.

Carboniferous Rocks.—Exposures of rocks containing fossils that have been determined as Carboniferous in age [6] were found in the southwestern part of the map-area along Shawnawdithit's Creek.

The fossils occur in poorly consolidated shales, arkose, and conglomerate, of strikingly variegated red and green color. Two thin beds of limestone are present. Pebbles of diabase, rhyolite porphyry, and granite are found in the conglomerate beds. Carbonaceous material and fossils are found in thin beds of shale near the top of the section. The dips are low, the beds lying nearly horizontal but showing gentle folds.

The rocks are so unique in color and lithology that some exposures along Red Indian Lake and Flynns Creek may be correlated with them with considerable confidence. On Flynns Creek they are flat-lying or have very low dips. Elsewhere along the shore of Red Indian Lake they show more pronounced dips, which is to be expected in view of the marked faulting close to and more or less parallel to the shores of the lake.

Structure.

The ore zone occupies a re-entrant of the Buchans Series to the north, in the granite intrusives. The present map does not cover enough of the surrounding country to show this well. Although the general strike of the Buchans Series is about N. 45° to 60° E. and dip 30° to 50° NW. the rocks diverge markedly from this

[6] Newell-Arbor, E. A., "A Note on Some Fossil Plants from Newfoundland," *Proc. Cambridge Philosophical Society*, vol. 15, pp. 390–392, 1910. Determination by H. S. Shimer of material collected by the writer supports the conclusion given by Arbor.

strike in the vicinity of Buchans. The strike in the map-area is in the form of a sigmoid curve, with the ore zone on the part of the curve that is convex north.

The total length of rocks involved in this sigmoid curve, measured along the strike, amounts to over eight miles.

Minor folds were seen at several places. The most marked faults in the map-area are found with NE.–SW. strike along Red Indian Lake. Near Skidders Brook, fault scarps may be seen with downfaulting on the lake side of the fault. A fault, probably of considerable throw, that strikes east-west, is found on Wiley's River below Wiley's Lakes. On Buchans River near the Buchans River ore bodies, a fault is indicated by the structural relations of the rocks. Several small strike faults are found south of these same ore bodies. Some faults with horizontal or low dipping fault surfaces are found on the eastern side of the Lucky Strike ore body and also along Buchans River above the Buchans River ore bodies.

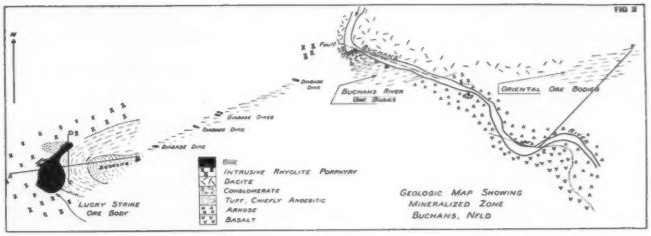
THE ORE BODIES.

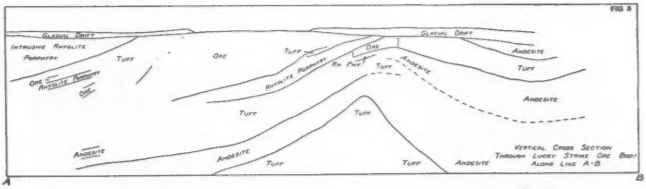
Intense mineralization is localized at three places along a general zone shown in Figs. 2–5. The Lucky Strike ore body is found at the western end, the Buchans River ore bodies in the central part, and the Oriental ore bodies, at the eastern end of the zone.

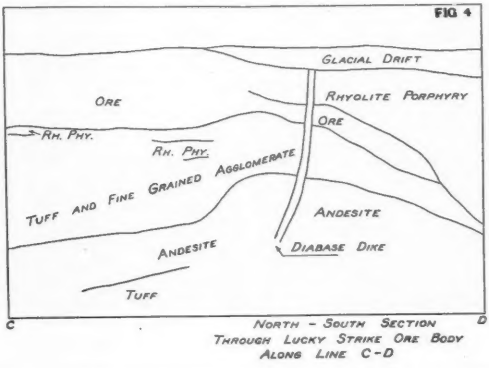
The ore was formed by almost complete replacement of the rocks, which produced a massive aggregate or mixture of sulphides and gangue minerals. The rocks replaced are chiefly broken and sheared tuffs, some rhyolite porphyry and minor amounts of lava flows, mainly at localities where the dip of the beds flattens upward. The main ore bodies also appear to be localized at places of change in the strike of the tuffs. Rhyolite porphyry is found close to all the ore occurrences.

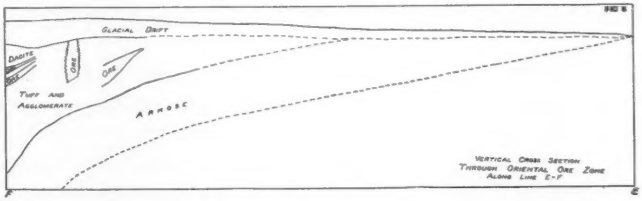
Ores and Mineralogy.—The five known ore bodies, of which the Lucky Strike is the largest, are estimated to contain 5,750,000 tons of ore, averaging:—Gold .033 ounces; silver 3.25 ounces; copper 1.4%; lead 7.65%; zinc 17.85%.[7]

[7] Guess, H. A., Vice-President, American Smelting and Refining Company. Report to Anglo-Newfoundland Development Company.









FIGS. 2–5. Plan and sections of ore zones, Lucky Strike ore body.

The ore is a massive, intimate mixture of fine-grained sphalerite, galena, pyrite, chalcopyrite, and very little tetrahedrite, with the gangue minerals barite, quartz and calcite. The large proportion of barite present is unusual in ore deposits.

The only mineral commonly showing well-developed crystal faces is pyrite. To judge by the relict pyrite crystals embedded in the massive ore sulphides which have in part replaced the pyrite, it usually formed euhedral or subhedral crystals as originally deposited, in what is now ore. Occasional masses of pyrite with concentric structure are found.

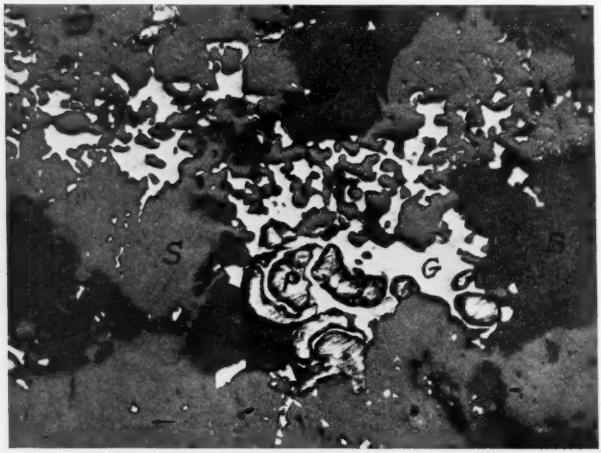


FIG. 6. Typical texture of galena and sphalerite ore. Galena (*G*) light gray; sphalerite (*S*) dark gray; pyrite (*P*) showing tendency toward concentric structure; barite (*B*) black. × 250. Lucky Strike ore body.

Most of the mineral grains are less than a few tenths of a millimeter in diameter, in the ore. Where other sulphides are not abundant the pyrite may form much larger grains.

Mineral Relations.—In hand specimen the sulphides appear intimately mixed, with bands or vein-like masses of chalcopyrite in parts of the ore, which on casual inspection appear to transect

cr cut the massive mixture of other ore minerals. Locally, the ore is well banded, and these bands may be traced into well-banded tuff beds which they have replaced with pseudomorphic preservation of the banding. Unreplaced remnants of the tuff beds showing the same relations have been found in the ore. The bands of minerals are hence due to selective replacement of banded rock. Some white calcite veins and white barite that veins the ore and lines vugs are clearly later than the ore minerals.

In polished and thin sections of the ore a definite sequence of minerals is found.

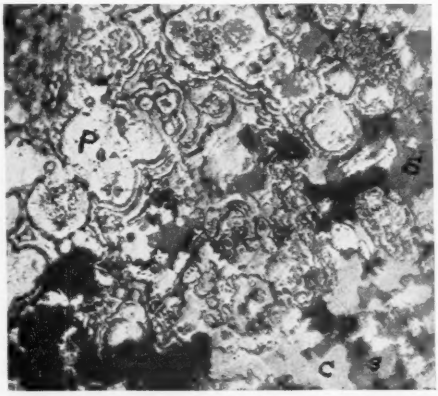


FIG. 7. Pyrite (*P*) light-colored mineral, forming concentric structures with sphalerite (*S*), gray, and chalcopyrite.

Chalcopyrite (*C*) about the same color as pyrite forms a vein-like mass transecting the concentric structure near the center of the figure. Black, gangue. × 250. Lucky Strike ore body.

Massive barite, usually gray in color, was the first mineral to form with the exception perhaps of some pyrite. It is one of the most abundant minerals. Near the ends or border of the Lucky Strike ore body, particularly on the southwest end and also on the northeast end it is high in proportion to the other minerals; some hand specimens appear to be almost solid barite. Small lenses of

it are found in the wall rock close to and approximately parallel to the ore contact of the Lucky Strike ore body. It thus occupies a similar position in space and time of deposition to that which the early mineral pyrite commonly fills in other districts in the pyritic replacement type of ore bodies.

The barite is much finer-grained than is common in vein barite. It forms scattered knots or roughly spherical-shaped masses one to several inches in diameter in a bed of conglomerate it has partly replaced along Buchans River. This occurrence is unique in the area, however.

Abundant minute veins of sulphides traverse it along small fractures or along its cleavage planes.

The general succession of mineral introduction is gray barite and pyrite, followed by sphalerite, then concentric masses of pyrite, chalcopyrite, galena with a few small grains of associated tetrahedrite. It is not known whether the minerals were in general deposited separately in time or with some or even considerable overlapping of deposition. No microscopic evidence on this point could be found. It can be argued by geochemical reasoning that since the minerals are intimately mixed and all of small size that they were deposited under about the same general concentration, temperature, and pressure conditions; in brief, that the mineralization took place in one general surge or period of introduction. This the writer believes is probably the case.

Plenty of evidence exists that the sulphides, galena and sphalerite especially, have replaced to some extent the barite; that chalcopyrite and sphalerite have partly replaced pyrite; and that chalcopyrite has partly replaced sphalerite. The evidence used is based on the conception of extrapolation and reconstruction of host structures, chiefly crystals, as outlined elsewhere.[8]

Later than the fine-grained massive sulphide ore, are rare small veinlets or vugs of well crystallized white barite, some with crystals an inch or more across, and calcite veins, both of which may contain pyrite crystals. The barite crystals are in one example coated with a thin yellow film, the composition of which has not

[8] National Research Council, Sub-Committee Report on Paragenesis of Ore Minerals. Forth-coming publication.

been determined. Small calcite crystals also may rest on the barite in vugs.

An unidentified mineral having optical properties suggesting a zeolite was found in a fracture in calcite.

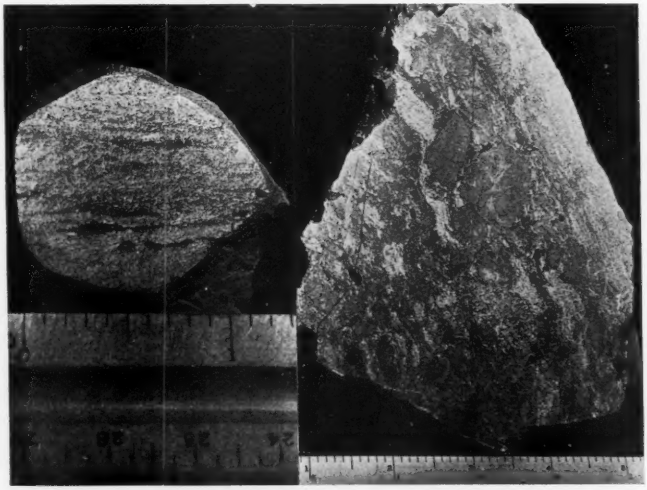


FIG. 8 (left). Banded ore. Dark colored bands are gangue and tuff, light colored ones are pyrite, sphalerite, and chalcopyrite. Buchans River ore body.

FIG. 9 (right). Mineralized conglomerate. Dark colored parts are rock and gangue minerals, showing pebbles, light colored parts are sulphides. The sulphides have selectively replaced the finer grained matrix of the coarser pebbles and fragments. Near Buchans River ore body.

Oxidation.—Pleistocene glaciation has removed part of the Lucky Strike ore body and probably also parts of the other ore bodies. Stripping of glacial debris at the Lucky Strike showed smooth surfaces of the ore with glacial striations in places. Only a thin film of oxidation material in places coats the fresh ore, this film being commonly only a few millimeters thick, but occasionally several centimeters. Fractures in the ore have permitted slight oxidation of thin films on the wall of the fractures, to some feet

beneath the surface. The compounds formed are limonite, malachite, anglesite, and covellite, with possibly others not identified.

Wall Rock Alteration.—The wall rock near the ore is often although not always highly altered. The andesite and andesite tuff have been changed to chlorite to such an extent, that the original character of the rock is locally obscured in the broken or sheared ground near the Lucky Strike ore body. Scattered pyrite crystals and local silicification are commonly found in the chloritic zones.

The broken and sheared rhyolite porphyry and some of the more light-colored siliceous tuffs are strongly silicified. The rhyolite porphyry and some of the tuff, immediately on the ore contact, where strongly sheared, have usually been changed almost wholly to sericite.

Structural Relations of the Ore.—The ore bodies appear to be in the same general stratigraphic horizon, although the beds vary in composition and texture along the strike, so that no definite bed can be traced along the entire zone.

Lucky Strike Ore Body.—At the Lucky Strike ore body the main mass of ore is located on the southwest nose of a domed anticline. Evidence is not complete on the exact shape of the dome. The axis of the ore body plunges with the dip of beds, down the axis of the fold. The smaller ore body that lies north of the main mass of ore at Lucky Strike, dips northwest approximately with the dip of the tuff beds. The banding of the tuff beds is here in several places pseudomorphically preserved with similarly oriented tuff relicts in the ore. It appears to be an essentially continuous mineralization of a favorable tuff horizon, out from the main ore mass, on the north limb of the fold. Some faulting has modified the fold on its north limb. Rhyolite porphyry forms the hanging wall, and may well have extended almost completely over the ore body (Figs. 2–5).

Buchans River Ore Bodies.—The Buchans River ore bodies lie in tuff beds. Some conglomerate, a coarse-grained phase of these sedimentary fragmental rocks, has been mineralized. The exact location of these ore bodies is not shown on Fig. 1. The ore in

the tuff beds, where exposed by stream action in the river, has clearly replaced certain beds, the ore showing unreplaced fragments of the tuff and pseudomorphically retaining the sedimentary banding. These ore bodies also occur at a slight bend in the strike, although this has been obscured by a fault along the river. The dips of the various beds involved in the rock section strongly suggest that the ore has replaced beds where the dips flattened somewhat on coming upward.

Rhyolite porphyry is found a few hundred feet northeast and also northwest of the ore.

Oriental Ore Bodies.—These are not individually shown in Fig. 1.

The fault along the river near the Buchans ore bodies is inferred from the fact that several hundred feet of sedimentary beds have been eliminated which should appear on the east side of the stream. It is reported that a fault was encountered in some old mine workings at this place. The northeast side is down-thrown relative to the southwest side. The fault zone appears to swing east from the river through the Oriental. The rocks in the vicinity of the Oriental ore bodies are strongly sheared.

Dacite appears to have been replaced to form part of the ore at the western end of the Oriental zone, although the ore may largely replace blocks of tuff in-faulted into the dacite. The evidence shown by the diamond drilling is not clear in this respect. In the east end of the Oriental the ore appears to replace tuffs. The ore has replaced the beds at a change in the dip, and the strike relations of the rocks along the river south of this place, along with other data, strongly suggest that the main mineralization took place near a bend in the strike as well.

ORIGIN OF THE ORE.

The ore was clearly introduced after the intrusion and fracturing of the rhyolite porphyry. Although the solutions that deposited the ore probably did not come from the rhyolite porphyry itself, they were doubtless derived from the same source—the granite magma. The main reason for the close association of ore

and rhyolite porphyry is probably that the ore solutions moved along the fractures associated with the intrusion. The reason for deposition of the ore near a change in dip of the beds, is not entirely clear, but may be due to the greater relative abundance of fracturing there, or in part to the damming effect on the solutions.

The reason for the marked replacement of tuffs as compared with other rocks, is probably due in part to the fact that it breaks readily with clean fractures. However, the tuffs appear to be more readily replaced than the other rocks even where not greatly fractured, possibly because of greater permeability of the solutions in this rock. The mineralization belongs to the mesothermal type of deposit as defined by Lindgren.[9] The presence of pyrite with concentric structure suggests that a part of the solutions may have been colloidal.

The fine-grained character of the ore may well be the result of deposition by relatively concentrated solutions, such as the colloidal suspensions which the metallic sulphides form with the alkaline sulphides.[10]

Although barite as a gangue mineral is common in small amounts in the pyritic copper ores of replacement origin, and in lead and silver deposits, the only occurrence of sulphide ore known to the writer which is comparable to this deposit in amount of associated barite is that at Meggen, Germany.[11]

The solutions in the early part of the deposition at Buchans probably contained the sulphate radical in unusual amount. It may be that the sulphate radical is commonly present in ore deposits in larger amounts than is generally supposed,[12] but that in this particular deposit, the barium was present in large amount to fix it in a stable mineral.

MASS. INSTITUTE OF TECHNOLOGY,
CAMBRIDGE, MASS.

[9] Lindgren, W., "Mineral Deposits," 1929.

[10] Freeman, Horace, "Genesis of Sulphide Ores," *Eng. and Min. Jour.*, 120, No. 25, p. 973, 1925. Kania, J. E. A., Thesis for Doctor's Degree, *Mass. Inst. Tech.*

[11] Beyschlag, Krusch-Vogt, "Die Lagerstätten der nützbaren Mineralien und Gesteine," pp. 808–813, 1921.

[12] B. S. Butler, "Primary Sulphate Minerals in Ore Deposits," ECON. GEOL., vol. 14, pp. 581–609, 1919.

A METHOD FOR SAMPLING MINERALS IN POLISHED SECTIONS.

MAURICE HAYCOCK.

AMONG the various methods which have been employed in the study of ores and ore minerals during the last few years, the use of microchemistry and the quartz spectrograph promise to be of great value as means of determining mineral species. Both methods are particularly applicable since only a very small amount of material is necessary, and this is an all-important factor when the minerals are finely intergrown. The problem of obtaining pure samples of minerals in polished sections has, however, received relatively little attention, most workers being content to follow the commonly accepted procedure of gouging the samples from the grains by hand with a needle.[1]

During 1929 and 1930, a study was made by the author of a suite of complex ores in which the minerals were very finely divided and of such a character that recourse was had to microchemistry and the quartz spectrograph. Much difficulty was encountered in procuring pure samples, the minerals being very hard and of a size impossible to drill out by any tool held in the hand. As a result of these difficulties an instrument has been devised which will drill any metallic mineral so far encountered. Moreover the drilling point will remain precisely on any grain with which it is brought in contact, although any area can be covered by traversing the specimen under the drill by means of a mechani-

[1] A device for obtaining material from mineral grains in polished sections was described by B. Granigg in 1915 (*Metall und Erz*, XII (N.F. III), p. 193, 1915). This device consisted of a hand-operated rotary drill which was mounted in the optic axis of the microscope, but since the axis of the drill was at right angles to the surface of the section it was necessary to remove the objective before drilling could be carried out. Recently a drill has been described by H. Moritz (*Centr. Miner. Abt.*, A (7), pp. 251–254, 1929) as having been developed and used successfully at Freiburg University. This apparatus is similar to a dental tool, and in fact dental drills were used as drilling points. The tool is held in the hand and drilling carried out while under observation with the microscope.

cal stage. The instrument is easy to operate and the results are thought to be better than those obtained by the most skilled operators of manual tools, since by its use it has been found possible to secure without difficulty an uncontaminated sample from a grain of hardness 6 and about 0.1 mm. in size.

The instrument consists essentially of a small electric motor on the shaft of which is mounted a needle. A bearing near the point of the needle obviates any tendency to wabble, and to this feature

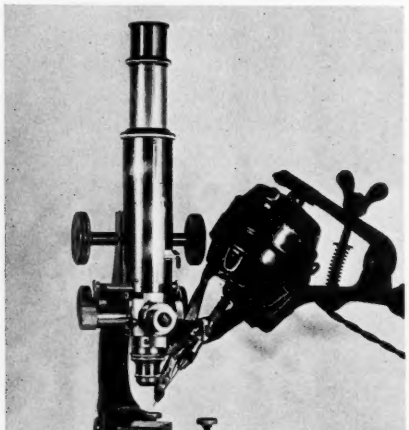


FIG. 1. The drill in position under the microscope. The stage has been lowered and the light source moved aside so as not to obstruct the view.

the apparatus owes a large part of its success. The instrument is mounted rigidly so that the needle point is in the optic axis of the microscope and at the elevation of the polished surface when in focus. Boring is carried out, not by moving the drill, but by moving the section, vertically by means of an adjustable stage,

and horizontally by hand or by means of a mechanical stage (Fig. 1).

CONSTRUCTION.

The drill is operated by means of a small electric motor of the type commonly employed with mechanical toys. One found to be well suited to the purpose [2] can be connected directly with the ordinary lighting circuit, into which is introduced a sliding resistance for controlling the speed. It is advisable to include also a switch, placed in an easily accessible position.

A small pin vise [3] was used as a means of mounting the needle. In order to shorten the distance from the motor to the needle point, about 2 inches was cut from the handle of the vise and it was then mounted by fitting the hollow handle tightly over the motor shaft. The shaft was slightly large but it was reduced in diameter to secure a snug fit by carefully pressing a file against it with the motor running. Care must be taken to have the pin vise mounted so that there will be no wabble. To steady the needle point a small bearing was placed about ¼ inch from the tip. It was made as follows: A needle similar to that which was to be used as a drill [4] was passed through a cork stopper so that its point coincided with the surface of the cork; then, with the cork pressed down on a piece of thin sheet brass resting on wood, the needle was driven about ¼ inch through the brass by tapping sharply with a light hammer. The brass was then trimmed with a file so as not to obscure vision when under the microscope (Fig. 2-*A*). This bearing was then soldered to a rigid arm which in turn was firmly secured to the motor by means of three small bolts. Needles may readily be inserted or removed without disturbing the adjustment of the mount.

Although the original plans provided for a more elaborate and rigid mount, very satisfactory results have been obtained by using a large clamp and a stand possessing a strong metal upright and a heavy base. The drill was so mounted in the clamp that its axis

[2] The motor used in this case is a "Polar Cub," Type H, operating on 110 volts, 60 cycle, A.C. or D.C., manufactured by A. C. Gilbert Co., New Haven, Conn.

[3] No. 162 C pin vise, manufactured by the L. S. Starrett Co., Athol, Mass.

[4] No. 6 Sharps have been found to give satisfactory results.

made an angle of about 60° with the plane of the section and the needle point was at the elevation of the polished surface when focused with a low power objective (Fig. 2-*A*).

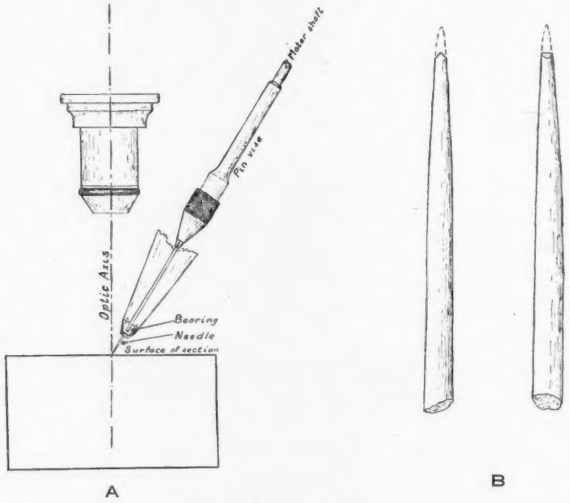


FIG. 2. *A*, Drawing to show position of the bearing. *B*, Type of point used in drilling hard minerals.

In general it has been found advisable to temper the needles before use. This may be done over a small flame. For fine work, especially with soft minerals, it was not found necessary to use other than the original point, but with large grains and with hard minerals a point such as is shown in Fig. 2-*B* has been found most satisfactory. Such a point was formed by touching the needle momentarily against a fine emery wheel. If very coarse drilling is to be done, it has been found advantageous to increase the speed of boring by producing a coarser point by longer grinding on the emery wheel.

OPERATION.

Since the drill is rigidly mounted and cannot easily be raised or lowered, it is necessary to use it in conjunction with a micro-

scope provided with a stage which can be adjusted vertically by means of rack and pinion (Fig. 1). After the needle has been inserted and the drill adjusted to the elevation of the polished surface when focused under a low power objective, the stage of

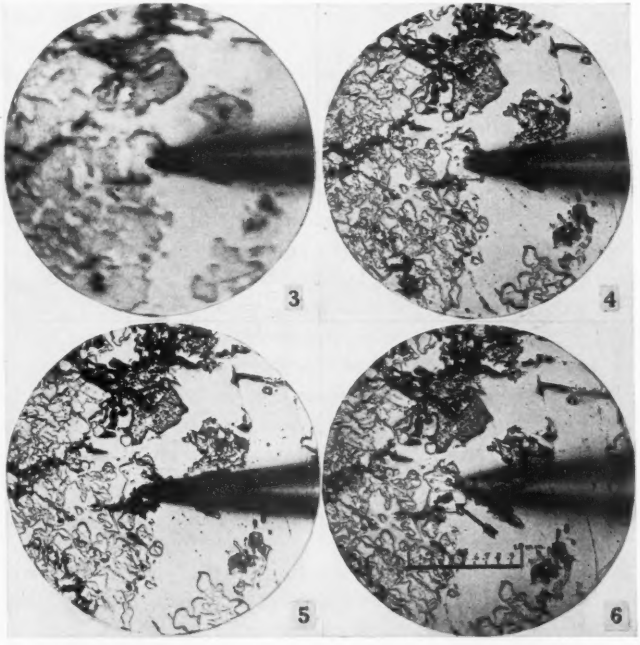


FIG. 3. The needle in position under the microscope. The polished surface is out of focus below the needle point. × 18.

FIG. 4. The microscope tube has been lowered to focus on the polished surface in order to select the grain to be drilled. The needle point is now out of focus. × 18.

FIG. 5. After the tube has been raised so that the microscope is focused again on the needle point the stage is raised until the contact is made with the grain selected. × 18. *This exposure was made while the drill was operating at a speed of about 200 r.p.m.* and the borings may be seen piling up at the point.

FIG. 6. The stage has been lowered and the section refocused after drilling. The cavity is indicated by the arrow. × 18.

the microscope is lowered slightly and the needle point moved horizontally into the field to a point preferably near the optic axis (Fig. 3). The tube is then lowered slightly, throwing the needle out of focus but bringing the polished surface into sharp focus (Fig. 4). The grain to be drilled is selected and placed directly under the needle point. The tube is raised to focus again on the point of the drill and the motor is started and its speed adjusted. The stage is now raised until the grain is brought into contact with the drill, the section at the same time coming to sharp focus. The borings will pile up around the point as shown in Fig. 5, which was exposed for 8 seconds while the drill was revolving at a speed of about 200 r.p.m. When sufficient material is obtained, or when the grain is drilled so far that there is danger of introducing impurities by boring into adjacent or underlying grains, the stage and tube may be lowered slightly (Fig. 6) and the material collected in the usual manner.

A speed of from 200 to 300 r.p.m. has been found most satisfactory. If it is much in excess of this the vibration will tend to scatter the borings and they will be lost.

With this apparatus it has been found possible to remove pure material from sections containing only very small grains, and excavations of less than 0.1 mm. in size have often been produced. Moreover, the depth to which the drill penetrates may be delicately controlled; copper-free samples of a nickel-iron sulphide with a hardness of over 5, intimately intergrown with chalcopyrite, have been secured by allowing the drill to touch only the hard mineral which stood up in relief above the chalcopyrite, and this section was not polished with the idea of producing relief, but was selected at random.

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THE TRANSPORTATION OF GOLD BY ORGANIC UNDERGROUND SOLUTIONS.

FRED. W. FREISE.

ALL mining companies or individual miners who have worked alluvial gold deposits in Brazil realize that gold placers thoroughly exhausted may after a period of years once more be panned and yield a profitable amount of newly accumulated gold. The native gold digger maintains that every gold placer within ten years is again valuable enough to be worked over once more and that the *pinta que paga, i.e.* the "paying spark" reappears the sooner if the exhausted gold field has been hidden from the sun by vegetation or other means.

The author worked gold placers at the eastern boundary of the State of Minas Geraes in the districts of Palma and Muriahé in 1908 and 1909 and for the second time in 1926; the first time monazitic sands were the principal object of the mining work, but the gold contents of the gravel (8.5 grams per ton) were recovered, since they almost defrayed the pay roll. But when, in 1926, the same places were opened again, an average of 4.85 grams of gold per ton was realized near the bottom rock, the metal being quite different from the original gold, both in color, purity, coarseness, and affinity to mercury. The nature of the territory and the sequence of the strata precludes the hypothesis of mechanical transfer from a higher point; the occurrence suggested that this gold had been brought to its place by chemical transportation.[1]

In the eastern part of the State of Rio, the author opened up some gold placers in 1912; the gold content of the gravel was 11.6 grams per ton, and the average yield was 10.85 grams. When, in 1926, the old diggings, quite overgrown with "caapœira"

[1] Details concerning the above-mentioned gold and monazitic deposits were published by the writer in *Zeit. f. d. Berg-, Huetten- u. Salinenwesen i. Preuss. Staate,* vol. LVII., pp. 47–64, 1910.

(second growth), were reopened, the lowest layers immediately above the granitic bed rock yielded 4.66 grams per ton, of a greenish variety of gold which chemically behaved quite differently from the commonly known allotropic modifications of gold.

Finally, an opportunity to see gold transported chemically by underground solutions was given to the writer in 1927, when he had occasion to examine the large tailing heaps accumulated by an important gold mining company in the center of Minas Geraes. These tailings generally showed 0.48 grams of gold per ton, but in certain parts overgrown by shrubberies there was found as much as 3.69 grams per ton. Since for the last twenty years or more the average ore treated assayed 9.5 to 10.2 grams and the recovery was 9.0 to 9.5, this high content in the tailings can hardly be ascribed to losses in milling and treatment, but must be attributed to accumulation after the tailings had been dumped.

These observations suggested an investigation into the nature of the agents that might have caused the transport of gold from its original point to lower levels. The physical and chemical properties of the original gold and the "new gold," as it may be called, were investigated. The specific gravity was determined by means of the specific-gravity bottle; the color and the surface were observed under the microscope; differences in hardness or in toughness could not be investigated since the particles of the new gold were too small. To examine the affinity to mercury, *i.e.* to see whether the new gold is a "free milling" or a "refractory" one, the gold samples were passed over copper plates of 4 to 6 inches, coated with a thin film of mercury. To determine the action of cyanide solutions on the two varieties of metal, carefully weighed portions of gold of the same degree of fineness were exposed to solutions of cyanide of potassium of various strengths for many days. The gold in solution was determined at equal intervals for both kinds of gold under treatment. The results of these tests are shown in Table I.

TABLE I.

PHYSICAL AND CHEMICAL PROPERTIES OF THE DIFFERENT KINDS OF GOLD OBSERVED.

Kind of Gold.	Spec. Gravity.	Color.	Surface.	% Metal Caught on Mercury.	% Gold Dissolved in KCN-solution of . . . % When in Contact during . . . Hours					
					.5		1.0		2.5	
					24	144	24	144	24	144
Common placer gold, 98.3% Au, 1.7% Cu	19,562	Yellow	Scarred	66.45	16.2	33.5	22.4	55.7	43.7	88.8
"New" gold, 100% Au	19,222	Greenish	Plain	18.38	3.5	11.8	10.1	48.2	21.4	44.5
"Black" gold, after crust was taken off. 100% Au	19,217	Greenish	Plain	16.66	2.9	11.5	9.9	40.4	19.7	43.9

It will be noted that the new gold is very refractory against mercury but is relatively more soluble in cyanide solutions.

It is remarkable that the physical and chemical properties of the new gold are, even in minute details, identical with those of the so-called "black gold" (*ouro preto*) found in Brazil at many places near the ancient State capital of Minas Geraes, which drew its name from the numerous deposits of "black gold" in its vicinity. These were worked out by the first discoverers in the districts of Itabirito, Diamantina, Sabará, Santa Barbara, São Gonçalo do Sapucahy, Carangola, all in Minas. Black gold is also commonly found in the districts of Rio Verde, Formosa, Santa Luzia in the State of Goyaz, and in the district of Santa Rita do Araguaya in Matto Grosso. The native prospector generally inadvertently throws it away with the heavy residuals in the pan, such as titanite, black garnet, magnetite, rutile, wolframite, and tourmaline; only by chance is it detected in the pan when the surface of the gold is given thorough attention. Black gold, as it is found at these places, is gold covered with a dark brown to dull black coating of 2 to 25μ in thickness; where larger grains of metal are found, they prove to be composed of several smaller individuals each of which preserves its own coating. A washing with a 5 per cent. solution of K_2CO_3 at a temperature of 35°–45° is sufficient in most cases to make the coating disappear;

where the coating is thicker, a cautious heating to 300°–330° is required, which is followed by a washing with dilute sulphuric acid. The sulphate of iron which is then formed has to be removed by washing before cyanide or other agents can be applied to the metal, which then shows its customary yellow color. The dark varieties of "black gold" show 0.22 to 0.35 per cent. of Fe_2O_3 and the browner ones, 2.85 to 3.5 per cent., in the coating. In so far as the writer's investigations go, it cannot be said whether there is only one kind of coating or several kinds; the brown one which was investigated can be considered as $C_2O_7H_{12}Fe$ (humate of iron).

The above considerations as to the character of the coating of the "black gold" flakes suggest that waters charged with organic acids formed by the decomposition of vegetable matter were responsible for the transportation of gold from higher to lower levels. To check this idea, several series of tests were made, first with an artificial product prepared from bituminous brown coal found in the vicinity of Carangola, Minas Geraes, and afterward with "black water" generated in virgin forests from centers of humification of decayed vegetation.

The brown coal contained 21.33 per cent. water, 15.62 per cent. ash, 36.28 per cent. fixed carbon, and 26.77 per cent. of volatile matter, and held in its combustible matter about 68 per cent. of substances soluble in alkali. According to the process indicated by Simek [2] this raw product was used to isolate a dark brown substance which, after a long period of drying, first in air, then in vacuum at 55° C., showed upon analysis 67.21 per cent. carbon, 4.98 per cent. hydrogen, 1.23 per cent. nitrogen, and 7 per cent. ash, of which the most important constituents were Fe_2O_3 and P_2O_5. Separation by solubility of the different components of this raw product was not tried; for the experiments described, solutions in water were used.

In order to determine the minimum concentration of such suspensions that would act upon free gold, carefully weighed quantities of gold in the form of plates of uniform granulation were exposed to solutions of known concentration contained in glass

[2] See *Brennstoff Chemie*, vol. 9, 1, 12, p. 381, 1928.

TABLE II. REACTIONS OF HUMIC ACIDS ON GOLD UNDER DIFFERENT CONDITIONS.

Strength of	Kind of Water.	Gold Experimented on.	Conditions.	Duration of Experiment. Hours	Dissolved.

TABLE II. Reactions of Humic Acids on Gold Under Different Conditions.

Strength of Solution.	Kind of Water.	Gold Experimented on.		Conditions.	Duration of Experiment. Hours.	Dissolved.	
		Shape.	Fineness.			Mg.	%
%							
.10	Rain water, airless	Plate, .01″	850/1000	No Motion	24	8,354	.05
					48	15,228	.91
		Dust, .01″	850/1000	"	24	11,182	1.14
					48	23,075	2.35
					72	25,553	2,59
.50	Rain water, airless	Plate, .01″	1000/1000	Constant Motion	24	2,134	.005
					48	2,664	.0062
	Rain water, aerated	Dust, .005″	1000/1000	"	24	Traces	0
					48	Traces	0
2.50	Dist. water, airless	Dust, .005–.1 mm.	900/1000	No Motion	24	32.551	3.68
					48	65.001	7.21
					72	97.161	11.08
4.00	Rain water, airless	Same material as before		Slow Motion	24	27.101	3.11
					96	111.402	12.50
					192	168.249	19.28
					300	175.455	20.21
10.00	Rain water	Dust, .002–.08 mm.	600/1000–975/1000	Slow Motion + air	24	23.450	1.56
					48	42.761	2.84
					72	70.111	4.66
					240	166.369	11.00
5.00	Dist. water	Gold precipitated by $FeSO_4$		No Motion	48	Traces	
					96	Little more	
10.00	Dist. water with 1% of K_2CO_3	Plate, .01″	900/1000	"	24	Traces	
					30	Reaction stopped	
10.00	Dist. water with 1% of K_2CO_3, 1% of $NaHCO_3$	Same material and same conditions of experiment			Suspension without effect		
10.00	Aq. dist. with .5% KNO_2, .5% KNO_3, .5% NaCl	Same material and same conditions of test			After 12 h. without any effect		
10.00	Water with .5% Na_2SO_4, .5% $CaHCO_3$	Identical material, under same conditions			Merely traces dissolved; after a few hours no effect whatever		

bottles that were kept in slow, continuous motion. In some instances distilled water free from air was used; in others, free access to the air was allowed. Another series of experiments was conducted under free admission of carbonic acid, and a third was carried on with water mineralized with one or more salts in the same concentration as in subsoil water. The results are shown in Table II.

The data of Table II. allow of the following conclusions:

1. Gold is attacked by humic acids, even those of a very dilute character, provided sufficient time is allowed and oxygen is excluded. Oxygen rapidly destroys the organic combination, as may readily be seen by the clarifying of the water from dark brown to chestnut and reddish yellow to gold yellow; clear brown suspensions are absolutely innocuous to gold metal, even in 20 per cent. solutions.

2. Distilled water and water freed from air maintain the organic acid solutions in their full activity for a considerable time; rain water is only slightly inferior. With natural waters, the different minerals contained in them act differently on the organic acids; e.g. the carbonates and bicarbonates are the first salts to destroy the humic acids in the water, then follow sulphates, bisulphates, and nitrates; chlorides seem to have but little effect on the stability of the organic acids. The writer has not as yet determined whether the susceptibility of the metal to solution varies with different temperatures; all experiments have been conducted at field temperatures.

3. The fineness of the original metal does not appear to influence the solubility in the humic acids, at least so far as silver, copper, and palladium, as constituents of the gold ore, are concerned. Differences can be noted, however, between the reactions of the acids on natural gold and on gold produced by precipitation. In the latter case, solubilities vary according to the precipitant used; metal precipitated by ferrous sulphate, for example, is less rapidly attacked than gold precipitated by oxalic acid. The causes of these differences have not yet been investigated; probably the different precipitates are different allotropic varieties of gold.

Following these investigations more elaborate experiments were made, utilizing moor water or black water from the Serra dos Aymorés, the divide between the States of Minas Geraes and Espirito Santo and one of the thickest virgin forest districts of the whole country.[3]

Observation shows that these waters, which are dark yellow to brown or black in color, absolutely clear and transparent, low in oxygen or free from it, and of a strong acid reaction, quickly attack all the easily soluble components of the rocks such as the combinations of K_2O, Na_2O, CaO, and MgO. A relative concentration of the iron and manganese hydroxides and oxides is followed by the destruction of these constituents; the alumina and phosphoric anhydride combinations, if not destroyed and transported, are at least affected. Finally there remains merely silicic acid free from any metallic accessories except oxides of tin, tungsten, titanium, and zirconium. Gold, silver, and palladium disappear among the first constituents destroyed.

There can be no doubt that the black waters transport metallic combinations in the form of definite chemical compounds and not by adsorption; formulas can be established for the majority of metals, *i.e.* iron, copper, and manganese, for their combination with humic acids, and this is true of gold also.

After the black water has dissolved the metals, contact with the open air is sufficient to oxidize the metals and to cause them to form a scum on the water surface, in the case of iron, copper, and manganese (and probably of some other common metals also). In the case of gold, however, other conditions are necessary to bring about its reappearance. Simple contact with the atmosphere is not sufficient to separate it, since oxygen does not act

[3] Under normal conditions, an acre of ground produces in this region about 3,500 cubic feet of timber, 8 to 11 per cent. of which decays annually (about 7.5 to 10.8 tons); 80 per cent. of this raw material disappears by quick fermentation which leaves only 5 per cent. or even less, equal to one eighth inch, as humus on the ground, while 20 per cent. suffers transformation under water, giving origin to the so-called black waters (*rios negros* or *rios pretos*) commonly noted on geographical maps of the tropics. Although these black waters are not so extensive in this part of Brazil as in the Amazon districts, or in Sumatra or Borneo, they carry annually thousands and thousands of tons of rock material in suspended colloidal form to the ocean or to deeper levels alongside the Rio Doce.

intensely enough on the gold humate; it is indispensable for the precipitation of gold that the gold humate in its underground circulation meet strongly mineralized waters such as carbonate or sulphate waters.[4]

While investigating a small placer gold deposit in one of the side valleys of the Rio Pancas, one of the affluents of the Rio Doce on the left which comes down from the center of the Serra dos Aymorés, the writer verified in an extensive series of experiments the processes of gold solution, transport, and redeposition that go on in nature in the manner described above. For this purpose a wooden flume six feet wide, four feet deep, and 50 feet long, was built with an inclination of one inch in three feet; this flume was filled for nine-tenths of its length with thoroughly washed sand of determined fineness, or with mixtures of sand and clay, or with pure kaolin, according to the details shown in Table III. The filling was evenly packed each time by means of water jets. The upper tenth of the flume was finally filled with sand, sand and clay, or pure kaolin, as in the longer part of the flume, but in this section there was admixed a carefully weighed amount of gold dust of known fineness and grain that could be recognized at once if panned out. Into this end of the flume was delivered a constant stream of black water derived from a nearby rivulet that carried from 6 to 10 per cent. of raw humus. Before the black water was introduced into the head of the flume, the whole flume was covered with water-tight boards. The amount of water allowed to sink into and pass through the flume filling was measured at the lower end by means of a tank fed by a pipe that passed through the bottom boards of the flume. This tank also permitted samples to be taken of the water that sank through the sand or other filling.

With each filling, one experiment lasted sixty days; at ten-day

[4] The conglomerates known by the name of *tapanhoancanga* or *canga* (nigger head) in Minas Geraes, famous for their gold and diamonds, are partly cemented by gold that originally circulated in solutions formed in the manner here described. It is highly probable that the deposits of lignite known and partly explored in the State of Minas are the remainders of those virgin forests that gave origin to the black waters which transported the gold solutions mentioned here.

TABLE III. TRANSPORTATION OF GOLD.

Flume Filling and Gold Admixed in mg./kg. of Filling	% of pores	Gold contents in mg./kg. verified after the following days of water run:																					
		10			20			30			40			50			60						
		at the following distances in feet from water inlet:																					
		15	30	45	15	30	45	15	30	45	15	30	45	15	30	45	15	30	45	15	30	45
Sand; 50 mg./kg.; dust of .1–.5 mm.	22	31	11	3	26	11	7	16	15	12	13	18	13	11	22	13	10	25	13				
Sand; 20 mg./kg.; dust of .05–.1 mm.	24	10	7	1	6	7	2	5	8	3	3	?	5	2	?	9	tr.	7	15				
Sand and clay 50/50; 25 mg./kg.; .05–.15 mm.	16	17	3	0	14	5	2	11	?	3	9	8	5	Not investigated			Not investigated						
Sand and clay 25/75; 30 mg./kg.; .08–.2 mm.	12	21	7	tr.	16	9	1	13	12	2	10	14	4	7	17	4	?	?	?				
Pure kaolin 45 mg./kg.; .1–.5 mm.	10	30	10	2	22	14	4	No observations made						17	11	7							

intervals samples were taken at definite points of the filling and at the water outlet; the results of these investigations are set down in Table III. The conclusions that may be drawn from these results are:

1. The rate of transportation of gold (and other metals also) from higher to deeper levels, depends upon the permeability of the soil; the more densely the soil is packed, the more difficultly the organic agents permeate; the finest slimes as they float away from concentrating tables, after they have settled in a tank are hardly penetrable by the organic waters.

2. Strata free from limestone and other carbonates give better results; *i.e.* they are more rapidly freed of their gold contents than limestone and other carbonate strata. The reason for this is probably the greater affinity of humic acids to these carbonates than to gold; the same fact is observed with iron-containing constituents of the stratum.

3. There can be no doubt that such organic suspensions as here described and applied are effective agents for transporting metals from one part of a mineral deposit to another, and that by them even the most minute traces of metallic matter are dissolved and transported.

4. For iron and manganese humates the process of re-deposition of the metals is rather evident but in the case of gold the re-precipitation depends upon the character of the mineral solutions that are circulating in the subsoil, and these cannot always be readily determined.

In soil science, the fact that iron components of the soil are transferred to deeper levels has become evident by the "hard pan" formation found in many places. In geology, the circumstances under which the later iron and manganese deposits have been formed must be linked with the activity of such organic waters as have been considered here. That, even to-day, similar agents may move metals, is a matter that can be investigated only under very favorable climatic conditions. It is likewise true in the case of gold deposits that intense field and laboratory research is bound to accumulate further evidence concerning the possibility that

black water on, and in, the ground, may form new workable deposits even to-day, where old deposits have been given up as exhausted.

It is not impossible that the observations and experiments here recorded may eventually have an economic bearing in providing a scientific basis for the finding of low-grade mineral deposits derived from placer or other sources. That question, however, will not be considered here.

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PRECIOUS AND ORNAMENTAL STONES OF RUSSIA.

SERGEY E. LAVROV.

AN attempt to estimate the economic value of the deposits of precious and ornamental stones in a country presents many difficulties because of (1) the ever changing fads and fancies affecting the selling price of gems, and (2) the nature of the mineral deposits from which gems are obtained.

The price of gems, like that of every other commodity, follows the law of supply and demand. The demand for a gem depends not only upon the beauty and rarity of the stone but is also quite frequently stimulated by artful methods and by psychological manifestations. A striking example of a psychological factor influencing the gem market is the late war. During that time the ruby became exceedingly unpopular in America, whereas in Russia, due to the Revolution, the red stones were in great demand. Clever advertising also plays an important rôle. For example, the ever increasing popularity of the diamond may be attributed, to a great extent, to clever advertising. Excessive zeal on the part of exploiters also has its effects. Commonly, a valuable gem may drop considerably in the price due to overproduction. Only strict control by well organized producers and distributors can prevent the pitfalls of over-supply and its consequences.

The mode of occurrence of precious stones influences the valuation of their deposits. Gem minerals are most often found in pegmatite dikes, or are derived from alluvial deposits that are the product of the mechanical concentration of disintegrated dikes, sheets, pipes, and other intrusive masses of igneous rocks. The pegmatite dikes, which are commonly composed of coarse crystalline minerals, develop under favorable circumstances enormously large crystals. Irregularities in the size of their components are characteristic of pegmatite dikes, and their distribution may be

very erratic. These eccentricities present a serious difficulty in arriving at an accurate valuation of a gemmiferous deposit.

The enormous popularity which the diamond enjoys places all the other gems in a position where their bid for favor is greatly overshadowed. A clearer picture of this relationship can be seen from the following estimate. Diamonds valued at $4,000,000,000 are worn in the United States. In 1928 about $57,000,000 worth of these gems, comprising about 1.4 per cent. of the total value of imports, were shipped into the country. The other precious stones imported were valued at only 9.7 per cent. of the value of the imported diamonds.

Bearing in mind all the above-mentioned factors, it is possible to analyze comprehensively the deposits of precious and ornamental stones in a country. Russia has deposits of both the precious and ornamental stones in appreciable quantities (see Table I.). By subdividing all stones of economic importance into two major divisions: (1) gems, (2) ornamental stones, the evaluation of the deposits is simplified.

TABLE I.

Mineral	*Chemical composition*	*Locality*	*Probable yearly production, carats*	*Supplies carats*
Emerald	$Be_3Al_2(SiO_3)_6$	Emerald Mine, Ural.	100,000	10,000,000
Alexandrite	$BeAl_2O_4$	" " "	1,000	100,000
Phenacite	Be_2SiO_4	" " "	5,000	7,000
Demantoid	$3CaOFe_2O_3SiO_2$	Tagil, Sisert Distr.	25,000	Unknown
Vorobyevite	$Be_3Al_2SiO_3$	Savatievo, Trans-Baikal	500	Small
Beryl	$Be_3Al_2(SiO_3)_6$	Mursinka, Trans-Baikal	10,000	Medium
Topaz	$(AlF)_2SiO_4$	Mursinka, Trans-Baikal	1,000	"
Tourmaline	$H_9Al_3(B.OH)_2Si_4O_{19}$	Mid. Ural and Trans-Baikal	8,000	"
			Production in pounds	*Pounds*
Amethyst	SiO_2	Mursinka District	200	Medium
Smoky Quartz	SiO_2	Middle Ural	540	"
Lazurite	$Na_4(NaS.Al)Al_2(SiO_4)_3$	Baikal District	3,600	"
Nephrite	CaMgFe Amphibole	Sayan Mountains	20,000	"
Marble Onyx	Calc. Carb.	Ahalzih, Armenia	10,000	"
Vesuvianite	Basic Calc. Al. Sil.	Ural Mountains	2,000	Large
Amazonite	Plagioclase	Ural, Ilmen Mts.	4,000	Large
Beloretsk Quartz	SiO_2	Altai Mts.	18,000 Lbs.	Large
Jasper	SiO_2	Altai Mts.	36,000	Large
Serpentine	Mg. Silicate	Mid Ural	7,200	Medium
Gagat	Hydr. Sil. of Mg and Mn	Balahansk, Irkutsk Distr.	10,800	Large
Obsidian	SiO_2	Georgia	7,200	Large
Selenite	$CaSO_4 2H_2O$	Kama river	72,000	Large
Aventurine	Sil. Al and Na Plagioclase	S. Ural	3,800	Medium
Labradorite.	Plagioclase	Kiev, Volinsk Distr.	1,000 Tons	Large

GEMS.

Precious stones of first magnitude and of which the supply is limited, such as the emerald, alexandrite, demantoid, vorobyevite, phenacite and sapphire are classified as gems. Stones such as topaz, tourmaline, amethyst, nephrite, malachite and lazurite, which are of mediocre value, are also considered in the gem group. Ornamental stones include the marble onyx, vesuvianite, amazonite, labradorite, jasper, serpentine, selenite, obsidian, hornstone, aventurine, and others.

Emerald:—One of the most important gems is undoubtedly the emerald from the Ural Emerald Mine. It is a beautiful gem of bright emerald-green color. It occurs in mica schist. Professor A. E. Fersman estimates that from the opening of the mine in 1830 up to the present time 36,000 pounds have been produced but only 500,000 carats were available for cutting purposes. Taking $7.50 per carat as an average price, the sum of $3,750,000 was obtained for that period. Since no definite system was followed in exploiting the Emerald Mine, some levels are worked out to a greater extent than others, making it difficult to give an estimate of the total contents of the deposit. A modest estimate, however, reveals the supply to be at least 10,000,000 carats suitable for cutting, which at $7.50 per carat amounts to $75,000,000. Due to the cessation of operations in Colombia and to the poor grade of emeralds produced in Alexander Co., Carolina, and in Australia, the chances are that prices will be higher, and that a total of $100,000,000 might be obtained for the Emerald Mine deposits. The yearly rate of production for two shafts and six working faces is about 100,000 carats.

Alexandrite:—This gem, of emerald-green color in daylight and beautiful columbine red by transmitted light, is found in association with the emerald at the Emerald Mine in the Ural Mountains. It composes only about 1 per cent. of the emeralds produced, hence its high price.

Phenacite:—Varying from a colorless gem to one of bright wine-yellow, pale rose, red, and brown, this stone is also found in the Emerald Mine. Supplies amount to approximately 7,000 pounds and could be sold at $2.00 per carat.

Demantoid:—This gem, grass-green to emerald-green in color, has a diamond-like luster. It is found in commercial quantities only in Russia, and if its deposits in Sisert should prove of appreciable quantity a production of 25,000 carats per annum could be expected. Four dollars per carat is a very conservative price.

Vorobyevite:—A beautiful gold-brown variety of this gem is found at Savatievo, near Nerchinsk, Siberia. Stones of good quality amounting only to a few hundred carats a year could be expected from this pit because the primitive methods used have rendered mining operations difficult. The gem would find a market exclusively in Russia since its quality is not on a par with those produced in the United States or Madagascar.

Some of the more important of the lesser gems are the following:

Beryl:—Several deposits of this mineral are known in Russia. Beryl is found in abundance at Adui River, and in the vicinity of Lake Baikal, Siberia. At Baikal the gems found are of excellent quality. Before the war, 10,000 a year were produced and absorbed by the Russian market. There was no export of beryl.

Topaz:—This mineral comes from the Ural Mountains, Alabashka, Ekaterinburg, Miask, Ilmen Mountains, Orenburg, Nerchinsk, and Lake Baikal. Its production is negligible and the gems are sold only in the domestic market. At Lake Baikal gems of good quality are found but the output is only about 1000 carats a year.

Tourmaline:—Tourmaline of good quality is found in the Lipovskaia Mine in the Ural Mountains. Gems of a cherry-red color are produced at the rate of about 8,000 carats per year.

Amethyst:—Clear purple or bluish violet varieties are found at Mursinsky, and these deposits are famed for their excellence. Among the light-colored varieties a few dark-colored gems are found, and these are most highly valued. Production amounts to about 200 pounds per year.

Lazurite:—This gem, of azure-blue to violet-blue in color, is found in abundant quantities in the Lake Baikal region and elsewhere. Its production may reach 3,600 pounds per annum. Although the Russian lazurite is not as beautiful as the Afghanistan

variety, it is of a better quality than that produced in South America.

Nephrite:—Nephrite varies in color from white to dark green and is used extensively in the Orient for utensils as well as ornaments. It is found in extensive deposits in the Sayan Mountains. A yearly export of 20,000 pounds would be possible.

Ornamental Stones.

The ornamental stones discussed below are of minor commercial value to Russia at present although many of them are found in great abundance.

Marble Onyx:—This mineral is found in Armenia. An output of 10,000 pounds a year could easily be reached although at present only the domestic market is available.

Vesuvianite:—These stones are found abundantly in the Ural Mountains. Production is estimated at 2,000 pounds a year.

Amazonite:—Amazonite is also found in the Ural Mountains but the best mine is buried under the second track of the Trans-Siberian Railroad. An annual supply of 4,000 pounds could be obtained.

Labradorite:—A great abundance of labradorite is found in Russia and is used for ornamental purposes. Annual production reaches about 1,000 tons.

Deposits of jaspar, serpentine, hornstone and jet are extensive and some of them are of very good quality. There are numerous other minerals which are used locally for ornamental and other purposes, such as aventurine, abundantly found in the Ural Mountains; obsidian from Georgia; gagat, found near Balagansk in the Irkutsk District, Siberia; and selenite from the Kama River region. Their production, however, is small and economically unimportant.

Acknowledgment is made to Professor A. E. Fersman for the statistical data found in his article entitled " Dragozenni i zvetnii kamni v Rossii " which appeared in *Gorni Jurnal,* volume 10.

Kellogg, Idaho.

EDITORIAL

SUPERGENE MARTITE.

There has, in recent years, appeared a growing tendency to ascribe the martitization of magnetite to the influence of ascending hot solutions. A notable example is Dr. Gruner's latest contribution to the discussion of the enrichment process in the Lake Superior iron ores.[1] Without wishing to deny the possibility of such a hypogene martitization even on a great scale, it seems necessary to sound a warning, when arguments in favor of this process are interpreted as they are by several investigators, as excluding the possibility that martite can ever form as a result of weathering. A number of examples may be produced against a too sweeping generalization with regard to the hypogene origin of martitization.

In an investigation of certain occurrences of soft iron ores in Central Sweden, carried out some years ago by Dr. N. H. Magnusson and the writer,[2] it was found that these ores, as now developed, are the results of two different types of weathering in magnetite bodies. The first process has been an enrichment by secondary siderite, in part distinctly colloform, mainly by the replacement of limestone gangue in the magnetite ore. It is concluded that the iron contained in this siderite was dissolved from magnetite in the upper parts of the ore bodies (now eroded) and redeposited at greater depths. A later stage has been characterized by extensive oxidation, the siderite changing to limonite, the magnetite to martite and partly to limonite. An excellent proof of the supergene character of this martitization is furnished by

[1] Gruner, J. W. ECON. GEOL., vol. 25, pp. 697 and 837, 1930.

[2] Per Geijer and Nils H. Magnusson: Mullmalmer i svenska järngruvor, Summary: The Occurrence of "Soft Ores" in Swedish Iron Mines, Sveriges Geol. Unders., Ser. C, 338.

the Taberg mine in Värmland (not to be confounded with the titaniferous iron ore deposit of Taberg in Småland) where both the weathered and the unweathered parts of the ore body have been well exposed through underground mining operations. The weathered zone is found to end downwards with an irregular surface against the unaltered ore. In this particular case, siderite has not been identified except on a small scale.

Another Swedish ore body furnishes material that is highly suggestive of supergene martitization, but not so decisively clear as in the case just described. The high-grade magnetite ore of Kiirunavaara is partly martitized and has been leached of a part of its phosphorus content.[3] This martitization has evidently been a process very much later than the series of igneous events that brought about the original deposition of the ore. Positive arguments for a supergene origin can be found in the fact that certain small copper veins in the same ore mountain constitute the only good examples of supergene copper enrichment so far proved in Sweden, where otherwise all evidence of such enrichments has been removed by the Pleistocene glaciation.

The magnetite deposits of Algarrobo, in Chile, are more or less completely martitized in the outcropping parts, but even comparatively shallow underground exposures reveal a higher percentage of magnetite.

From the Edough district in Algeria, Dussert[4] reports that the magnetite is mixed with hematite in the upper portions of the ore bodies, but very poor in it at great depths. Phosphorus and sulphur are lower in the hematitic parts, and iron higher.

It is quite true that, as recently pointed out by Gruner,[5] there has been a striking absence of oxidation of magnetite at the surface after the Ice Age. But it must be remembered that, also, from a similar starting-point, the possibility of secondary enrichment of copper, at least on a great scale, might be questioned.

[3] Per Geijer: Some Swedish occurrences of bornite and chalcocite, Sveriges Geol. Unders., Ser. C, 321.

[4] Étude sur les gisements de fer de l'Algérie, Annales des Mines, 1912, p. 222.

[5] *Op. cit.*, p. 851.

Supergene martitization evidently does not take place under every kind of climatic conditions. Just what the requirements are remains to be found out.

The views here presented must not be interpreted as excluding the possibility that martitization may also be brought about by hypogene processes.

PER GEIJER.

DISCUSSION AND COMMUNICATIONS

ORIGIN OF SEDIMENTARY WHITE CLAYS.

Sir: Mr. George I. Adams in a recent paper [1] has proposed a new theory for the origin of some of the sedimentary white clays of the south Atlantic coastal plain. He suggests that, since the clay lenses are thin and of small extent, they were deposited by overloaded streams that crossed the coastal plain. He also suggests that the massiveness of the clays may be "the result of the local alteration of deposits of impure clays." Furthermore, Mr. Adams calls attention to the fact that the white clays of the Tuscaloosa formation in western Alabama rest upon and were derived from peneplained sedimentary rocks of Paleozoic age and hence he is of the opinion that the formation of a white residuum seems inapplicable to the conditions under which the Tuscaloosa formation was deposited.

So far as known the Tuscaloosa formation in western Alabama is succeeded conformably by the Eutaw formation, which consists of brownish colored sands and clays of shallow-water marine origin. The clays occur in small lenses and some of these marine layers contain plant fossils. Marine fossils and glauconite occur in the lower part of the formation. Since the Eutaw is of marine origin and rests conformably on the Tuscaloosa white sands and clays, it certainly suggests that the Tuscaloosa formation may be of shallow-water marine origin.

Berry, in a paper [2] on the Upper Cretaceous floras of Alabama and adjacent states, mentions traces of glauconite layers in the

[1] Adams, G. I., "Origin of the White Clays of Tuscaloosa Age (Upper Cretaceous) in Alabama, Georgia and South Carolina," ECON. GEOL., vol. 25, pp. 621–626, 1930.

[2] Berry, E. W., "Upper Cretaceous Floras of the Eastern Gulf Region in Tennessee, Mississippi, Alabama, and Georgia," *U. S. Geol. Surv.*, Prof. Paper 112, p. 26, 1919.

Tuscaloosa sediments. The presence of glauconite indicates marine conditions.[3]

The mere fact that the clay lenses of the Tuscaloosa are thin and of small extent is in itself no reason for believing that they are not of marine origin. Many of the clay lenses in the marine formations above the Tuscaloosa are of small extent.

If the clays were deposited by overloaded streams, as suggested, one might expect to find some indications of stream channels, but so far as the writer knows, no such evidence has been found.

Mr. Adams is of the opinion that the coagulating influence of salt water as a cause of rapid and continuous deposition of the clay to form massive beds, as suggested by Neumann,[4] is seldom operative. There are many references to this subject in geologic literature and it is probable that coagulation of clays by salt water is of greater importance than appears to be accorded it.[5] No evidence has been advanced to show that the massiveness of the Tuscaloosa white clays is the result of local alteration of impure clays, indeed, some of the white clays are at present being altered to bauxitic clays.[6]

The long period of pre-Tuscaloosa weathering produced a large peneplain upon which the igneous and metamorphic as well as the sedimentary rocks suffered weathering and erosion. During this long period of chemical weathering the soluble minerals were carried away and kaolinite and other persistent minerals were left on the peneplain.[7]

It is possible that the non-feldspathic sedimentary rocks of

[3] Goldman, M. I., "General Character, Mode of Occurrence and Origin of Glauconite," *Jour. Wash. Acad. Sci.*, vol. 9, p. 502, 1919.

[4] Neumann, F. R., "Origin of the Cretaceous White Clays of South Carolina," ECON. GEOL., vol. 22, pp. 374–387, 1927.

[5] Johnston, W. A., "Sedimentation of the Fraser River Delta," *Jour. Geol.*, vol. 30, pp. 115–129, 1922. Also Clarke, F. W., "Data of Geochemistry," *U. S. Geol. Surv.*, Bull. 770, pp. 509–510, 1924.

[6] Shearer, H. K., "Bauxites and Fullers Earth of the Coastal Plain of Georgia." *Ga. Geol. Surv.*, Bull. 31, 1917. Also Stull, R. T. and Bole, G. A., "Beneficiation and Utilization of Georgia Clays," *U. S. Bur. Mines*, Bull. 252, 1926.

[7] Neumann, F. R., *op. cit.*, pp. 382–385. Also Woolnough, W. G., "Origin of White Clays and Bauxite and Chemical Criteria of Peneplanation," ECON. GEOL., vol. 23, pp. 887–894, 1928.

Paleozoic age in northeastern Alabama did not weather to so pure a white residuum as the feldspathic igneous and metamorphic rocks of the Piedmont region of eastern Alabama, Georgia and South Carolina. Hence the Tuscaloosa clays of Alabama derived from the sedimentary rocks would not be as pure as the clays derived from the highly feldspathic rocks of Georgia and Carolina.

In summary, it might be reiterated [8] that there is still good reason to believe that the Tuscaloosa white clays are of shallow-water marine origin; that the massiveness of the white clay lenses is reasonably explained by coagulation in salt water; and that a long period of peneplanation and chemical weathering produced a white residuum that was later carried to the sea and deposited as lenses of white clay and sand in the shallow water near shore.

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THE STABILITY RELATIONS OF GOETHITE AND HEMATITE.

Sir: In the article entitled "The stability relations of goethite and hematite," [1] Dr. G. Tunell and Dr. E. Posnjak criticize a statement as to the stability of limonite occurring in my paper entitled "Hydrothermal oxidation and leaching experiments; their bearing on the origin of Lake Superior hematite-limonite ores." [2]

It is unfortunate that an article by E. Posnjak and H. E. Merwin entitled "The system Fe_2O_3–SO_3–H_2O" [3] was unknown to me when I prepared my manuscript. This oversight was due chiefly to the fact that a number of late references [4] which I consulted did not cite this article. I stated in my paper with reference to the apparent stability of limonite, "this very peculiar

[8] Neumann, F. R., *op. cit.*, pp. 386–387.

[1] ECON. GEOL., vol. 26, pp. 337–343, 1931.

[2] ECON. GEOL., vol. 25, pp. 697–719, 837–867.

[3] *Jour. Amer. Chem. Soc.*, vol. 44, p. 1965, 1922.

[4] Doelter, C., Handbuch der Mineralchemie, vol. III, 2d half, p. 668, 1926; Stirnemann, E., *Neues Jahrb. Beil.*, Band 52, A, p. 334, 1925; Böhm, J., *Zeitsch. anorg. Chem.*, vol. 149, p. 203, 1925.

behavior of ferric hydroxide at 250° C. and 300° C. will be investigated further." About 50 experiments which I have made since, some of them over periods of 90 days, give rather erratic results. But they do show that goethite is unstable at these temperatures, as well as at 200° C. Incidentally I may mention that in no case was I able to dehydrate natural hydroxide completely at these temperatures in sealed tubes in the presence of water. From 2.5 to 3 per cent. of H_2O remained with the substance.

The number of experiments on the stability of ferric hydroxide described in the literature is very large and much confusion existed until a short time ago. Even now, after this excellent work by Posnjak and Merwin, there is still some doubt (at least in my mind) as to whether the stability field of goethite does not extend above 140° C. Posnjak and Merwin made their experiments in solutions which were acid, though weak.[5] They reason by induction from the behavior of these dilute acid systems that in the binary system Fe_2O_3–H_2O as the limit, the high point of the stability field of $Fe_2O_3 \cdot H_2O$ should be very nearly the same as that in the very dilute acids. Tunell and Posnjak[6] cite an experiment, however, in which goethite in a very weak HCl solution (N/10) was changed to hematite at 100° C. There is then a very considerable difference (at least apparently) between the system containing the HCl and that containing SO_3. If the system Fe_2O_3–HCl–H_2O had been investigated first by Posnjak and Merwin, would it not have been likely that the transition temperature of $Fe_2O_3 \cdot H_2O$ to Fe_2O_3 might have been fixed near 100° C.? On the basis of these observations and those of 1919 by Posnjak and Merwin[7] one could also conclude that in the binary system Fe_2O_3–H_2O *alone* the transition temperature might be higher, possibly 160° C. or more.

To conjecture as to the effect of basic solutions on the stability field of goethite would take us into a new system of which the binary system Fe_2O_3–H_2O again would be the limit.

[5] Their weakest solution at 140° C. was about N/5 H_2SO_4 in experiment No. 72, in which they obtained hematite. In experiment No. 112 at 130° C. they obtained goethite in a N/10 H_2SO_4 solution. *Op. cit.*, pp. 1976 and 1973 respectively.

[6] *Op. cit.* p. 338.

[7] The hydrated ferric oxides: *Amer. Jour. Sci.*, vol. 47, p. 311, 1919.

Böhm [8] reports the formation of goethite (x-ray evidence) in a 2N·KOH solution from a hydroxide gel at 150° C. It is conceivable that such a basic solution, though not necessarily affecting the stability field, could enable $Fe_2O_3 \cdot H_2O$ to exist for very long periods.

Assuming that 140° C., as found by Posnjak and Merwin, is the approximate maximum temperature of the stability field of limonite in the system Fe_2O_3–SO_3–H_2O, the pressure in a very dilute solution at 140° C. will be about 3.6 atm. It would be of interest to investigate the stability at higher pressures, for after all 3.6 atm. pressure would be reached hydrostatically at a depth of about 120 feet. Since the molecular volume of goethite ($Fe_2O_3 \cdot H_2O$) is 41.52 (density 4.28 [9]), that of water 18.00, and that of hematite (Fe_2O_3) 30.38 (density 5.257), it would seem that higher pressures could extend the stability field of goethite upward, though such an increase might be slight. I have some apparatus under construction which will enable me to test the effect of a definite increase of pressure in this system.

I am criticized by Tunell and Posnjak for using the term limonite instead of goethite. It seems to me that this criticism is not justified, for the material I used was not much closer to $Fe_2O_3 \cdot H_2O$ in composition than the material usually called limonite. Even the synthetic goethite of Posnjak and Merwin [10] did not conform to the formula $Fe_2O_3 \cdot H_2O$, as analysis showed 3 per cent. SO_3 and a considerable excess of water. It was therefore a mixture. That such a mixture gives the x-ray diffraction pattern of goethite is obvious, for this mineral is vastly in excess. The patterns of any other crystalline substances in the mixture are too faint to be visible. I doubt whether it will be possible to dispense with such convenient terms as limonite in the case of extremely fine-grained mixtures of ferric hydroxide with SiO_2 and other compounds.

I am aware that color alone can not be used for distinguishing between Fe_2O_3 and $Fe_2O_3 \cdot H_2O$, though Tunell and Posnjak seem

[8] *Op. cit.*, p. 212.

[9] Posnjak, E., and Merwin, H. E., *Am. Jour. Sci.*, vol. 47, p. 347, 1919.

[10] *Jour. Am. Chem. Soc.*, vol. 44, p. 1972, 1922.

to think that I am ignorant of this fact because I wrote with respect to oxidation to a yellowish or light brownish substance in some experiments, that the product was "probably limonite." There were, however, no other means of determining exceedingly thin films of oxidation on powdered material. It is true that in one experiment probably enough material for x-ray examination was available. Unfortunately all this material was used for the determination of H_2O. A recent repetition of this experiment yielded a much smaller amount of oxidized material. Microscopic study showed that it was not goethite, but was probably hematite (turgite). Though it is probable that goethite is not stable above 140° C. it is possible that it can form and exist for long periods as a metastable product somewhat above this temperature ("formation fields and existence fields of Tunnell and Posnjak"). This might very well be the case in the decomposition of ferrous silicates like greenalite, which perhaps takes place in a number of complicated steps.

The probability that goethite is unstable above 140° C. does not imply, however, that those Lake Superior ores containing limonite were concentrated by weathering, but it indicates that the temperatures were probably somewhat lower than 200° C. as was originally stated.[11] Recent experiments which can not be described here point to such a condition.

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[11] Gruner, J. W., *op. cit.*, p. 867.

REVIEWS

Physiography of the Western United States. By NEVIN M. FENNEMAN. Pp. 534, illus. 173, map. McGraw-Hill Book Co., New York, 1931. Price, $5.00.

The author has given us in this volume a readable and clear account of the physical features of the United States west of the Mississippi Valley. The topics discussed are provinces of the Great Plains, the Southern Rocky Mountains, the Wyoming Basin, the Middle and the Southern Rocky Mountains, the Columbia Plateau, the Colorado Plateaus, the Basin and Range, the Sierra Cascade and the Pacific border. The treatment is naturally mostly descriptive, but the geological causes of the structures in each province are outlined, and the characteristic elements of each subdivision are delineated. One of the most valuable features of the book is the geographical demarkation of the various provinces and of their many subdivisions. The volume is well printed and satisfactorily illustrated and is furnished with abundant references. The comprehensiveness of the treatment is such that a resume of the book's contents is practically impossible. Its purpose, in the words of its author, is to summarize the present knowledge of the physiography of the western country so that it may "furnish a consistent frame in which additional knowledge and more local discussions may find a setting." It may be consulted with profit by economic geologists who are interested in the physiographic and geological setting of the western ore deposits. The halftones which illustrate the text, while well selected, would have been clearer and more attractive had they been printed on a paper more suitable for the purpose.

W. S. BAYLEY.

The Glacial Geology of Connecticut. By RICHARD FOSTER FLINT. Pp. 294, pls. 64, figs. 42. Connecticut State Geol. and Nat. Hist. Survey, Bull. 47, 1930.

From a detailed study of the glacial deposits of Connecticut the author has developed an interpretation of the last ice age that runs counter to long-entrenched beliefs. In short, the gravels that have hitherto been generally considered as of glaciofluvial origin are considered to be chiefly glaciolacustrine. Most of the so-called river terraces were found to

have ice-contact frontal slopes and their longitudinal profiles are horizontal instead of sloping upstream; and the gravels of the terraces show foreset bedding.

Even more arresting is the hypothesis that the New England ice sheet of the Wisconsin epoch lost its capacity to flow during its waning stage: it became stagnant and gradually wasted away *in situ*. As the ice melted it shrank away from the sides of the valleys in which it was confined, and there came into existence a series of ephemeral marginal lakes, whose levels were determined by ice walls and bedrock spillways. To cap the climax, the ice sheet is held to have melted from north to south; and the last remnant of the once mighty ice sheet to disappear was that occupying the trough of Long Island Sound, then free of water because the level of the world-ocean had been lowered 150 feet by the withdrawal of that much water in the Pleistocene ice sheets.

These conclusions are based upon a detailed State-wide study of the distribution and the characters of the gravels. The distribution of the glacial deposits is shown in colors on a State map of Connecticut on a scale of 1:125,000, which accompanies the report. It must be conceded that the new interpretation accounts more simply for many hitherto puzzling features in the glacial deposits of the State.

Although this study was not intended for economic ends, any such investigation that brings us one approximation nearer the truth is sure to have unforeseen economic importance; and as a matter of fact this work has already led to the discovery of sand and gravel deposits.

ADOLPH KNOPF.

Handbook for Prospectors. By M. W. VON BERNEWITZ. 2d edit. Pp. 359, figs. 89, glossary. McGraw-Hill Book Co., New York, 1931. Price, $3.00.

This handy limp-covered pocket volume is completely revised and largely rewritten. Part I deals with field conditions. Part II (76 pp.) treats briefly of the elements of mineralogy, general geology, ore deposits, outcrops, prospecting, sampling, field tests, and technology. Part III (165 pp.) is a condensed text on minerals and their occurrence, detection, description and uses. Part IV (39 pp.) is an addition on geophysical prospecting. A 40-page glossary is a valuable feature.

The book is well written and illustrated and should prove of great value to engineers, geologists, and students in the field. Much of it will probably be above the heads of most prospectors but those eager to learn will obtain much desirable and valuable information from it.

ALAN BATEMAN.

A Year on the Great Barrier Reef. By C. M. YONGE. Pp. xx + 246, pls. 70, figs. 17, maps 6. Putnam, London and New York, 1930. Price, $6.00.

This book has a broad interest that makes an appeal to every department of knowledge. It is distinctly a popular account (though in no unworthy meaning of that phrase) of the actual work and experiences of members of the Great Barrier Reef Expedition, 1928–29, written by the leader of the enterprise. It deals largely with the materials with which the expedition was concerned—corals and the Great Barrier, which is their most magnificent creation. The vivid picture of the inhabitants of the coral islands and of their physical and living environment gives the book its chief interest and value.

Those who are interested in the reef-building corals, whether from the biological, geological, or economic aspect, can hardly afford to ignore the work. The results obtained by the expedition include much that is new, and this readable account is valuable as a forecast of the strictly scientific memoirs which will appear in due course. Geologists, especially, cannot fail to find interest in the picture of the battle between the corals and the elements with which they contend, such as the effects of the prevailing winds, and of heavy rainstorms. The geological background to all this, though not emphasized, is by no means obscured or distorted.

The work is illustrated by a number of diagrams, maps, and seventy full page plates. Most of these are very fine and clear; a few, especially the views from the airplane, are however, disappointing.

It has seemed to the reviewer that there are one or two small inaccuracies noticeable in the distribution chart of reefs, and in the idea expressed that Pleistocene glaciation consisted in a thickening and extension of polar ice-caps. With regard to the latter, it may be remarked that it is now fairly well known that glaciation consisted rather in the accumulation of ice sheets principally in middle latitudes. But these are not matters of great consequence to the general reader to whom the book is primarily addressed.

On the whole the diction is clear and strong and the typography is excellent. The author has given us a fascinating volume and, at the same time, has accomplished one of his purposes, that of avoiding in general the technicalities of the scientist, as well as the sensationalism of the journalist.

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Geologie de la Mediterranée occidentale. Vol. I (1929–30). Pt. I. Pp. xliv; 1–72; pls. 9, figs. 5, maps 2. Pt. II, pp. 72–100, pls. 14; figs. 24; maps 2. Barcelona, 1930.

These are two of a series of publications relating to the 14th International Geologic Congress held in Spain in 1926. They are not official publications of the Congress but are gotten out independently under the editorship of Professor J. M. Riba of Barcelona. They deal particularly with that part of the Congress relating to Catalonia. Excursions and itineraries in that region are outlined, also certain papers relating to the western Mediterranean region that appeared during and subsequent to the Congress. There is also a bibliography of all papers by congressionalists relating to these regions that have appeared between 1926 and 1930.

BOOKS RECEIVED

Die Magmagesteine der Geosynklinale von Nowaja Semlja. By H. G. BACKLUND. Pp. 63, pls. 5. Norweg. Exped. to Nowaya Zemlya, 1921, Rept. 45. Norske Vidensk. Akad., Oslo, 1930. (In German.)

Two Polar Maps, with Notes on Recent Polar Exploration. By L. G .JOERG. 2d edit. Pp. 95, figs. 9. Amer. Geograph. Society, Spec. Pub. 11. New York, 1930. The maps, on a scale of 1:20,000,000, depict all known features; the text treats of all explorations since 1925.

Peru from the Air. By G. R. JOHNSON, with text and notes by R. R. PLATT. Pp. 159, figs. 152. Amer. Geograph. Society, Spec. Pub. 12. New York, 1930. A series of aerial photographs and accompanying text (printed on double-sized pages) illustrating the topography of Peru. Magnificent photographs of great geological interest.

Names and Definitions of the Geologic Units of California. Compiled by M. G. WILMARTH. Pp. 97. U. S. Geol. Surv. Bull. 826, 1931. Price, 20 cts.

Contributions to Economic Geology, 1930. Pt. II, Mineral Fuels. U. S. Geol. Surv. Bull 822, 1931. Price, 30 cts.

The Greek Element in English Words. By J. C. SMOCK. Pp. 356. Macmillan Co., New York, 1931 (Feb.). Price, $15.00. Prepared by a former State Geologist of New Jersey to demonstrate the part played by Greek words in English and to provide initiators of scientific nomenclature with desirable reference lists. There is an alphabetical list of English words derived from Greek, and Greek words with their English dependents. The register contains 130,000 English words. Useful to scientists.

Re-forming Natural Gas. By W. W. ODELL. Pp. 54, figs. 16. U. S. Bur. Mines Tech. Paper 483, 1930. Price, 10 cts.

Stream Gaging in Arkansas from 1857 to 1928. By W. S. FRAME. Pp. 149, pls. 3, figs. 2. Price, cloth $1.90, paper $1.40. Ark. Geol.

Surv. Stream Gaging Rept. 1, Little Rock, 1930. Stream flows from 1857 to 1928, and water power information.

Chemistry of Leaching Bornite. By J. D. SULLIVAN. Pp. 20, figs. 7. U. S. Bur. of Mines, Tech. Paper 486, 1931. Price, 10 cts.

A Note on the Geology of the Country around Tendaguru, Lindi District, Tanganyika. By J. PARKINSON. Pp. 16, figs. 7. Geol. Surv. Dept., Tanganyika, Short Paper 6, Dodoma, 1930. Price, 2 s.

Bibliography of North American Geology, 1919–1928. By J. M. NICKLES. Pp. 1005. U. S. Geol. Surv. Bull. 823. Washington, 1931. Price, $1.25 (paper).

Surface Water Supply of the United States, 1926. *Pt. XII.* North Pacific Slope Drainage Basins. *B.* Snake River Basin. Pp. 263. U. S. Geol. Surv. W. S. Paper 633, 1931. Price, 40 cts.

Analyses of Wyoming Coals. Pp. 159, figs. 2. U. S. Bur. of Mines, Tech. Paper 484, 1931. Price, 25 cts.

The Geology of the Country between Gatooma and Battlefields (Southern Rhodesia). By A. M. MCGREGOR. Pp. 144, pls. 14, figs. 8. Geol. Surv. Bull. 17. Salisbury, So. Rhodesia, 1930. Price, 4/9. General geology; petrology of acid and basic intrusives, with new rock analyses; formation of auriferous veins and lodes; mineralogical changes in wall rocks of gold reefs; other miscellaneous economic deposits. A valuable bulletin.

Records of the Geological Society of India, Vol. LXIII, Part 4, 1930. Pp. 72 + 51. Calcutta, 1930. Includes: Modern oilfield practice, by C. T. BARBER; Undescribed freshwater molluscs, India and Burma, by B. PRASHAD; Northwest Himalayan Earthquake, by A. L. COULSON; and miscellaneous notes on tremolite, sapphirine, and titaniferous augite.

Universal Drehtischmethoden. By M. REINHARD. Pp. 119, figs. 49, tables 5. B. Wepf & Cie, Basel, 1931. Price, unbound, $2.00, bound, $2.40.

Coal in India: The Gondwana System and Related Formations. By C. S. FOX. Pp. 241, pls. 10. Memoirs, Geol. Surv. of India, vol. LVIII, Calcutta, 1931. Price, 9s. 9d. One of a series on Indian coals. This volume is devoted to stratigraphy and paleontology.

Nitrogen and Its Compounds. By B. L. JOHNSON. Pp. 33, figs. 4. U. S. Bur. of Mines, Information Circ., Jan. 1931. Generalities; fixation; world industry.

Phosphate Rock: Pt. I, General Information. By B. L. JOHNSON. U. S. Bur. of Mines, Information Circ., March 1930. Distribution; prospecting; mining; technology; statistics.

Copies of books mentioned under "Reviews" or under our "New Book List" (see advertisement page) may be purchased through our Journal Bookshop by writing to W. S. Bayley, University of Illinois, Urbana, Ill.

SCIENTIFIC NOTES AND NEWS

Sydney H. Ball and Stanislaus Skowronski are on the Engineering Societies Monographs Committee, representing the A. I. M. E. This committee was recently formed for the publication of technical treatises which on account of length or specialization have not been available for publication in journals or in book form. The publishers of this series will be the Engineering Societies Library.

Charles Camsell has been given the gold medal conferred by the Institution of Mining and Metallurgy on account of his work in promoting the mineral industry in Canada.

D. J. Fisher, associate professor of geology at the University of Chicago, has returned after several months spent abroad.

M. W. von Bernewitz, who for some years has been at the Pittsburgh Experiment Station, U. S. Bureau of Mines, is now in the Health and Safety Branch at Washington, D. C.

G. A. Watermeyer, professor of mining in the University of the Witwatersrand, has been elected President of the Geological Society of South Africa.

Louis B. Schlichter has recently been appointed associate professor in the geology department of the Massachusetts Institute of Technology, Cambridge, Mass. He has been engaged in the mathematical study of scientific geophysical problems at the California Institute of Technology, and will work along similar lines in his present position.

E. P. Hindes has taken the position of chief geologist for Henry L. Doherty and Company, New York City.

Philip D. Wilson is spending two or three months in England and the Continent.

T. Wayland Vaughn, of the Scripps Institution of Oceanography, La Jolla, California, is a member of the advisory committee of the International Hydrographical Bureau of Monaco on a "General Bathymetric Chart of the Oceans."

C. P. Dunbar, who has been doing work for the U. S. Government in Haiti, is now paleontologist of the minerals division, Louisiana Conservation Commission, at Shreveport.

R. E. Stewart, of the Chanslor-Canfield Midway Oil Company, Ventura, California, is lecturing on petroleum geology in the University of South-

ern California during the absence of A. J. Tieje of the geology department.

H. Foster Bain of New York City has been in London recently.

J. Coggin Brown of London has returned from a visit to Burma.

W. J. Wilson has returned to London from Nigeria.

The Society of Petroleum Geophysicists, Houston, Texas, announces its officers for the coming year as follows: president, Donald C. Barton, Houston; vice-president, G. H. Westby, Empire Oil and Refining Company, Bartlesville, Oklahoma; secretary-treasurer, John F. Weinzierl, Houston; editor, Paul Weaver, Gulf Production Company, Houston.

The Kansas Geological Society will hold its Fifth Annual Conference from August 30 to September 5, in the Wichita and Arbuckle Mountains of Oklahoma and the Ouachita Mountains of southeastern Oklahoma and western Arkansas, under the leadership of C. N. Gould, G. C. Branner, C. E. Decker, Frank Gouin, O. W. Honess, H. D. Miser. N. W. Bass, Wichita, Kansas, is chairman of the field committee. Seven papers on geological history and problems will be given at the evening sessions.

The Committee on Organization, 16th International Geological Congress, has voted to postpone the meeting of the Congress for a year, to June, 1933. It was felt that the generally adverse economic conditions throughout the world made this postponement desirable.

The following topics for discussion have been tentatively adopted; Measurement of geologic time by any method; Batholiths and related intrusives; Zonal relations of metalliferous deposits; Major division of the Paleozoic system; Geomorphogenic processes in arid regions and their resulting forms and products; Fossil man and contemporary faunas; Orogenesis.

The routes of the excursions have been selected and work is well advanced on the preparation of the guide books. A circular is now being prepared giving more detailed information. This will be sent to all those who received the first circular and to others interested who request it from the Secretary, 16th International Geological Congress, U. S. Geological Survey, Washington, D. C.

The recently published 20-volume index (336 pages) of ECONOMIC GEOLOGY for 1905 to 1925, compiled by J. M. Nickles, may be obtained for $3.00 from W. S. Bayley, University of Illinois, Urbana, Ill.